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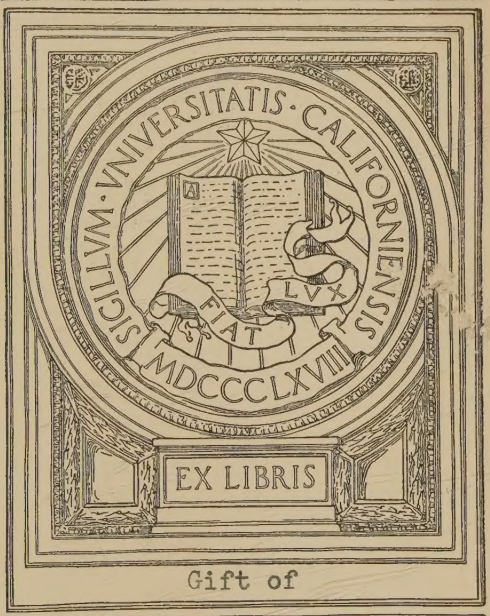

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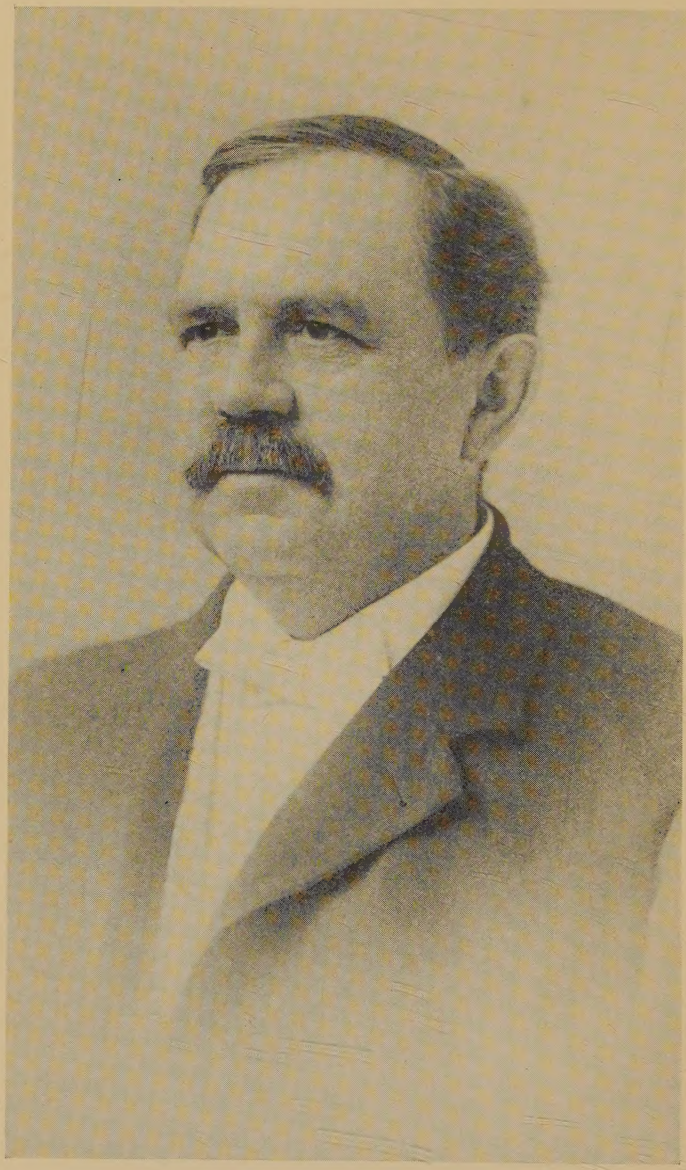
THE EXCHANGE OF ENERGY BETWEEN MAN AND THE ENVIRONMENT



W. O. ATWATER

The first great American to devote his life to the study of nutrition

THE EXCHANGE OF ENERGY BETWEEN MAN AND THE ENVIRONMENT

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PREFACE

THE MATERIALS dealt with were originally presented as a course of lectures to junior medical students at the University of Michigan. The object was primarily to enlarge their conception of the life processes.

Since measureable phenomena permit the mind to obtain the most concrete idea of a mechanism, the quantitative analysis of the manner in which man deals with the potential energy at his disposal, offers an unusual opportunity for the comprehension of a fundamental relationship upon which the living organism is entirely dependent.

There is no intention to familiarize the student with the unavoidable technical details of measurement or to furnish him with methods which he may use in the practice of medicine. Nevertheless, it is true that the conceptions dealt with have already shown their eminently practical value in a better understanding of such conditions as diseases of the thyroid gland and by offering a rational basis for the dietetic treatment of disease. These ideas have been our means of arriving at an understanding of the nature of obesity. Their use have made it possible to obtain a quantitative statement of the water exchange.

Since the subject matter of these lectures has not heretofore been brought together in this simple consecutive way, we have thought it worth while to make this material more generally available.

CONTENTS

Preface vii

Introduction xi

Part I. Calorimetry

CHAPTER PAGE

I. General Considerations 3

II. Historical Development 6

III. Present Day Methods of Measuring Energy Transformations 27

IV. Energy Transformations Under Various Conditions 38

Part II. The Insensible Loss of Weight

V. The Nature of the Insensible Loss of Weight 55

VI. Environment and Insensible Loss 65

VII. Applications 72

VIII. The Systematic Determination of the Character of the Energy Exchange 89

Conclusion 95

Index 97

INTRODUCTION

THE SCIENCE of nutrition concerns itself with (1) the quantitative study of the sources and transformations of energy and (2) with certain qualitative features of the food. Food in the broadest sense may be thought of as the total supply of beneficial materials which enter the organism from the outside. It must not only be considered as a source of energy, but of equal importance is knowledge of its quality. It includes oxygen; water; the three main sources of energy in the form of protein, fat and carbohydrate; the vitamins, and the inorganic salts. Oxygen is an essential part of the mechanism that makes the potential energy available. Water is needed to dissolve the products of digestion so that they may pass from the lumen of the gut, which in the teleological sense, is outside the organism, into the fluids of the body. It serves also as an essential vehicle for removing waste products, and of equal importance is its use in the dissipation of heat from the body by the process of vaporization.

The metabolism of protein like that of fat and carbohydrate yields energy. Protein is seemingly not as well adapted to that purpose as the other two food stuffs, since only about two-thirds of its energy is available to the body. It has, however, a special function, since its digestion products, the amino acids, are the materials with which the body builds and restores the major part of its tissue.

The quality of the protein needs most careful consideration, since the ideal in this regard is achieved when the protein of the diet supplies a mixture of amino acids which furnishes the organism exactly what it needs without waste.

The requirement for protein is not increased by work, nor can protein be stored in the body for future use. On the other hand, the excessive use of animal tissue as a means of supplying protein is capable of damaging the organism. The ideal intake of protein is an amount that each day exactly supplies materials needed for growth and repair. In the presence of a maintenance supply of energy, two-thirds of a gram of good protein per kilogram of body weight is more than sufficient.

Fat and carbohydrate are primarily packages of potential energy. Both may be stored in the body. The carbohydrate is laid aside in the liver as glycogen. When this organ is well stocked, any extra carbohydrate is then stored as fat. Fat absorbed in excess of that used is stored as such. There is a gradation in the storage capacity of the organism with regard to the three energy-yielding foods. In the case of protein, it is negligible, carbohydrate may be put in reserve to the extent of a few hundred grams, whereas no limit is known for the storage of fat. It is not uncommon for the weight of the adipose tissue in obese individuals to exceed the weight of active protoplasm.

Further, it appears to be true that the organism must

oxidize some carbohydrate in order that the fat may be completely burned.

One of the great triumphs of modern medicine is the recognition that certain substances, collectively called vitamins, are as necessary for the organism as any other substance obtained from the environment. To Eijkman, the Dutchman; Hopkins, the Englishman; and Hölst, the Scandinavian, we gladly give credit for having first appreciated the fundamental importance of these accessory food substances. These materials can have no energy value in themselves, because they are present in such minute quantities. They are often spoken of as catalysts, enzymes, or hormones, but their mode of action is not understood.

The inorganic salts are needed by the organism for several purposes. Bones and teeth require a plentiful supply of calcium and phosphorous. Hemoglobin cannot be formed without iron, while the thyroid gland cannot function normally without a supply of iodine. The fluids of the body contain definite amounts of inorganic salts resulting in solutions reminiscent of ocean water.

These various qualitative features thus far indicated are all brought together under the heading of "Dietetics."[1]

As already pointed out, it is not our purpose to more

[1] This phase of nutrition has been excellently treated by E. V. McCollum in "The Newer Knowledge of Nutrition", 1929, 4th. Edition, Macmillan & Co., New York; and by H. C. Sherman in "Chemistry of Food and Nutrition", 1924, 2nd. Edition, Macmillan & Co., New York.

than mention these qualitative requirements. Our desire is to discuss quantitatively the field of nutrition that deals with the sources and transformations of energy.

PART I

CALORIMETRY

CHAPTER I

GENERAL CONSIDERATIONS CONCERNING ENERGY

ENERGY is indestructible. Any form of energy is convertible into any other form. Heat is a manifestation of energy in its most disorganized state, and all energy tends to be dissipated in this manner. For example, a quantity of gasoline which has stored in it a certain amount of potential energy, may be caused to explode in the presence of oxygen by application of a minute, negligible amount of heat. The complex molecules composing the gasoline have been disrupted by this process. The large comparatively quiet molecules which we call gasoline have been broken up into small particles which are now moving rapidly in all directions. When this process occurs in the open, the friction of the particles bumping against each other is recognized as a burst of heat. The heat continues to be felt for only an instant because these particles fly off into the atmosphere at the same time losing motion and reducing the chance of collision. When the explosion occurs in an enclosed space such as a piston box, the particles are given the same initial impetus, and thus produce the same initial heat but are checked in their motion soon by impact with the piston and sides of the box. Since the piston is movable, some of the motion of the particles is converted

into the movement of the piston. Work then is done at the expense of heat. In this way, ultimately, the motion of all the particles is reduced with a resulting diminution in heat production. The initial heat, were it determined, would be a measure of the total energy of the process. In practice, the total energy is determined by measuring the heat dissipated and adding to it the thermal equivalent of the work done. The unit of heat is that amount required to raise one gram of water one degree centigrade, and is called the calorie.

In the case of the perfect engine, all of the potential energy would be convertible into work, and none would be lost as heat. This ideal is never achieved, since all forms of energy tend to become completely disorganized, and be dissipated as heat. Recognition of this fact is expressed in the term "efficiency." For example: the internal combustion engine is about 25 per cent efficient; the steam engine about 8 per cent and the human machine is 23-33 per cent.[2]

The living organism, like the engine, converts potential energy to its kinetic form through the processes of oxidation. When dealing with its energy transformations, the large calorie, which has a value of one thousand times that of the calorie defined above, is always employed. The engine is able to obtain kinetic energy only in proportion as it is supplied with fuel. It cannot store any

[2] The mechanical equivalent of heat is 1 calorie = .4267 kilogram-meters of work.

excess to be used later, when the supply is cut off. Furthermore, the rate at which it transforms energy is controllable by the rate at which oxygen is furnished. The living organism conducts itself in these respects in a totally different manner. In the first place, it has an established rate of energy transformations, nearly independent of the supply. Furthermore, it is able to store potential energy and thus can function efficiently for a long time in the absence of an exogenous supply. Finally its rate of oxidation is not augmented by increasing the supply of oxygen. Clearly, it ceases to function in the absence of oxygen, since potential energy is converted to its kinetic form through the process of oxidation.

CHAPTER II

HISTORICAL DEVELOPMENT

It is interesting to appreciate, how modern the fundamental conception of combustion is. The world had to wait for Lavoisier to show that the heat of combustion results from oxidation, that is the union of organic materials with oxygen, and the subsequent formation of carbon dioxide and water. As has been so often the case in the past, these brilliant contributions cost him his head since Marât who at that time was in control of the affairs of the French revolution had previously committed himself to a statement of the mechanism of combustion which was at variance with that of Lavoisier. The dominant idea regarding combustion up to that time had been expressed by the formulation of the Phlogiston Theory of Stahl (1660-1734)—a German scientist and physician to the king of Prussia. This theory postulated that all substances contained phlogiston which they lost when they burned; that oxides of lead, iron, etc., were metals which had lost their phlogiston. If these oxides were heated with carbon, a substance supposed to be rich in phlogiston they absorbed phlogiston and again became metals. Stahl evidently belonged to the group of "Nature Philosophers," that is a type of individual who does not feel it necessary to test his ideas by experiment. Had

he taken the trouble to weigh the metals before and after heating, he would have found that the postulated loss of something called Phlogiston by him must have in truth been a gain. Nevertheless this theory held the minds of the scientific world captive for a hundred years.

Joseph Priestly (1733-1804) heated the red oxide of mercury and obtained a gas in which a candle burned vigorously. He was a clergyman and had accordingly been trained to respect authority. It was therefore natural for him to explain his finding in view of Stahl's misconception. He called his gas "dephlogisticated air."

Scheele (1742-1786), a Swedish Chemist independently made oxygen by decomposing manganese dioxide. He likewise failed to appreciate the significance of his findings because he accepted the phlogiston theory.

In this same period, certain fundamental discoveries were made which paved the way for the work of Lavoisier. Joseph Black (1729-1799) produced and studied the properties of carbon dioxide called "fixed air" by him. Hydrogen was obtained by Cavendish in 1766. He thought it was Phlogiston. Rutherford, a pupil of Black's, in 1772, burned a candle in a closed space, absorbed "the fixed air," carbon dioxide, and observed that some air was left. He called this "Residual air." We would call it Nitrogen.

Such was the background against which Lavoisier (1743-1794) did his glorious work. He was the fortunate possessor of great intelligence, a fine education and

wealth, and lived at a time when great interest was displayed in the acquisition of new knowledge. But behind all of these was the driving force of character which combined these attributes in a way that laid the fundamental basis of modern chemistry and nutrition.

His laboratory philosophy is expressed in the statement taken from his "Elements of Chemistry" published in 1799, "As the usefulness and accuracy of chemistry depends entirely upon the determination of the weights of the ingredients and products both before and after experiments, too much precision cannot be employed in this part of the subject. . . . ."

His interest in the quantitative aspects of science is evidenced by the excellence of some of his apparatus which may still be seen in a museum in Paris. One may there see among other things a balance accurate to a tenth of a milligram, barometers, gasmeters, and ice calorimeters.

Lavoisier as a result of the work of his predecessors and contemporaries realized the existence of four gases, which were associated with processes of respiration and combustion. By means of his accurate methods he showed that animals removed what was shortly to be called oxygen from the air and contributed carbon dioxide to it; that if the latter were removed by absorption by alkali, there remained a third gas called azote by Lavoisier because it was incapable of supporting life. From his own experiments he came to the conclusion that the

phlogiston theory of Stahl was incorrect and in 1783 he wrote "All the phenomena of combustion and calcination are much more readily explained without phlogiston than with phlogiston." His conception of combustion implied the union of oxygen with carbon to form carbon dioxide, in other words, our modern view of this process. He likewise suspected that this same process was the source of animal heat and turned his attention to a study of this question. He now performed the first experiment in animal calorimetry. With a physicist La Place he calculated from the amount of ice which was melted by a guinea pig in a calorimeter, the heat given off by the animal. He also collected the carbon dioxide given off by a guinea pig, and from the weight of the carbon dioxide, calculated the heat which resulted from the oxidation of the carbon. The two calculations agreed closely enough so that he concluded that the source of animal heat was the oxidation of carbon. By comparing the respiration of guinea pigs in pure oxygen, a mixture of oxygen and hydrogen and air, he found that the nitrogen played no part in the respiratory process.

The culmination of his contributions consisted in the study of man himself. His co-worker Seguin was the subject. They found that man absorbed least oxygen in the fasting state at a comfortable temperature. When the temperature was very low—the oxygen absorption was slightly increased. Food caused a much greater increase and work resulted in a trebling of the amount of

oxygen absorbed. We today recognize these observations as basic facts.

The work of Lavoisier was abruptly cut short in 1794, through the misguided fury of members of the French Revolution. Marât who was at this time in charge of the Revolutionary party was responsible for his execution. A minor charge was brought against him as an excuse for the crime, but the real reason is to be found in the jealousy and bigotry of Marât, who even though the possessor of a liberal education, proceeded in the manner characteristic of a politician. Marât a few years earlier had committed himself to an opinion about the nature of fire. His view was a phantastic misconception quite out of accord with the lucid explanations of the great investigator. His bitterness is reflected in a phrase taken from a pamphlet published by him at this time, in which he speaks of Lavoisier as "The putative father of all the discoveries that are noised about, having no ideas of his own, snatches at those of others. . . . ."

In 1823 stimulated by the work of Lavoisier, the French Academy of Science offered a prize for the best Dissertation on animal heat. Despretz received the prize but the most fundamental contribution to the subject, as we now understand, was made by Dulong, who observed herbivora took in less oxygen for a given amount of expired carbon dioxide than did carnivora. Dulong thought this difference was caused by the nature of the diet characteristic of the two species. This was the first sugges-

tion of our present day conception of the Respiratory Quotient. During this period the great French Chemist Dumas to whom Pasteur attributed so much of his own success was making important advances in the knowledge of organic compounds. Magendie, meanwhile had come to think of the foodstuffs under three heads: fat, carbohydrate and protein. He recognized that protein differed from the other two materials in that it alone could rebuild body tissue.

In 1849 Regnault and Reiset—who by this time were satisfied that oxidation was the main source of animal heat—devised a closed system type of apparatus, which permitted them to measure the oxygen intake as well as the carbon dioxide output. The principle of the apparatus is today used in the construction of most clinical types of apparatus for the determination of metabolic rates. Regnault and Reiset were impressed by the fact that the ratio between exhaled carbon dioxide and inspired oxygen varied with the nature of the food fed. When meat was fed the ratio was the same as in starvation. Hence they believed that the fasting organism maintains itself by burning fat and protein. These men eighty years ago committed themselves to the pessimistic view that, while the animal heat was essentially due to the oxidative processes, the reactions were so complex that oxygen intake could never be used as a simple measure of heat production.

About a half a century had now elapsed since Lavoi-

sier explained the processes of combustion. During this time there had been consistent progress in the right direction. For our purposes perhaps the most important contributions dealt with the nature of protein and the knowledge of its metabolism.

Liebig the "so-called father of organic chemistry" suggested in 1842 that since protein contains nitrogen, the nitrogen of the urine might be a measure of protein destruction in the body. He developed an accurate method for the determination of the urinary nitrogen. In the same year Dumas and Cahours observed that 15-16 grams of nitrogen ingested in the diet were recoverable in the 30-33 grams of urea which were excreted in the subsequent urine. Bidder and Schmidt made the first careful experiments dealing with the relation between ingested and excretory nitrogen. They were able to recover in the urine and stool of cats and dogs nearly all the nitrogen which was fed as meat. Their experiments, however did not appear to be entirely convincing and it remained for Carl Voit to show conclusively that the nitrogen of the excreta is a true measure of protein destruction. The following experiment carries with it complete conviction. Voit fed a dog for 58 days 29 kilograms of meat, which contained 986 grams of nitrogen and found excreted in the urine and feces 982.8 grams. From this and other experiments of Voit it became evident that other paths of excretion of nitrogen must be insignificant.

Later investigators have determined the amount of ni-

trogen lost through the sweat and in the growth of the hair and nails and have shown that these amounts make up so small a fraction of the total nitrogen excretion that for all practical purposes they may therefore be neglected.

Since meat protein had been found to have an average nitrogen content of 16 percent, and since all the nitrogen ingested in this way was recoverable in the excreta, it became evident that every gram of nitrogen in the urine and feces must represent the breakdown of 6.25 grams of protein. These important experiments led to the conception that an excretion of nitrogen greater than the ingestion—represents a destruction of tissue protein, while the converse represents a retention of nitrogen.

Voit realized that the complexity of the metabolic processes were now unraveling. Of the three food stuffs he was certainly able to determine quantitatively the extent of the protein metabolism. Furthermore Regnault and Reiset had postulated that the fasting organism lived on fat and protein. Accordingly it became clear to Voit that if he measured the total carbon excretion and from it subtracted the carbon of the protein burned, the remaining carbon would be a measure of the fat destroyed. Further he argued that the oxygen necessary to complete the oxidation of the carbon and hydrogen contained in the protein and fat would equal the actual amount of oxygen absorbed by the individual during the experiment. Consequently he and Pettenkofer built a machine to carry out this experiment.

Their apparatus consisted of a chamber in which the man was placed. This chamber was well ventilated with a current of air, which was inspired through a meter so that its volume could be measured. The carbon dioxide and water content were also determined. Analyses were made from time to time to determine the carbon dioxide and water content of the air leaving the chamber, by passing it through sulphuric acid to remove the water; then through baryta to remove the carbon dioxide; then through a small gas-meter where the volume of the sample was measured. If they knew the carbon dioxide and water entering and leaving the chamber, it would be possible to calculate how much was derived from the man living in it. The apparatus was checked by burning a candle or evaporating a known weight of water in it. Carbon dioxide and water were measurable to within one percent. The oxygen absorbed was determined by difference. With this apparatus they studied a man who was essentially in the fasting state but in order to discomfort him as little as possible, they allowed him a small amount of Liebig's extract. They determined the total carbon excretion, the total nitrogen excretion and the oxygen absorption. Details of the experiment follow.

	Kg.		*Kg.*
Initial weight of subject	71.090	Final weight of subject	70.160
Water drunk	1.0548	Carbon Dioxide	0.7383
		Water of Respiration	0.8289
		Urine	1.1975
	72.1448		72.9247

In this manner all the factors which effected a change in weight, except the oxygen absorbed were measured. It was therefore possible to determine the latter by difference. The weight of the oxygen was accordingly 72.9247 — 72.1448 = 0.7799 kilogram.

They next determined the magnitude of the protein metabolism. The urine contained 12.51 grams of nitrogen. Since the subject ingested 1.18 gm nitrogen in the form of Liebig's extract only 11.33 grams of nitrogen had come from the destruction of body protein. Hence, they knew that the subject oxidized 70.81 grams of protein derived from his body.

Their next effort consisted in calculating what part of the total carbon excretion was attributable to a non-protein source. To do this they first obtained the total carbon excretion by adding to the respiratory carbon the urinary carbon, that is 201.3 grams and 8.25 grams = 209.55 grams. But the ingested Liebig's extract contained 2.44 grams, leaving 207.11 grams derived from the body. Since they knew that in the protein molecule there exists 3.28 times as much carbon as nitrogen, it was obvious that for every gram of urinary nitrogen 3.28 grams of carbon resulted from the breakdown of protein. Therefore, the 11.33 grams of urinary nitrogen represented 37.16 grams of carbon. Accordingly of the 207.11 grams of carbon which left the body, only 37.16 grams came from the oxidation of protein, leaving 169.95 grams of carbon which must have been derived from non-pro-

tein sources. Pettenkofer and Voit attributed all of this carbon to fat and since fat contains 76.52 per cent of carbon, they calculated that the subject burned 222.1 grams of fat. Therefore, this man according to them, maintained himself by the destruction of 71 grams of protein and 222 grams of fat—all furnished by his own body.

They were now prepared to see whether confirmatory evidence could be obtained by comparing the weight of the oxygen absorbed which they had determined, with the theoretical amount which must be added to complete the oxidation of the carbon and hydrogen in the above mentioned amount of fat and protein. Their calculation follows:

	Carbon Gms	*Hydrogen* Gms	*Oxygen* Gms
Protein	37.16	5.8	17.1
Fat	169.95	25.7	25.1
Total	207.11	31.5	42.2
There were excreted in the urine	8.2	2.0	7.6
Leaving for the respiration	198.9	29.5	24.6

Oxygen required for 198.9 gm. C: = 530.4 gm.
for 29.5 gm. H: = 235.7 gm.

Total ..... 766.1 gm.

Oxygen present in fat and protein minus oxygen excreted in urine ..... 34.6 gms.
Oxygen which must be added to complete oxidation of fat and protein ..... 731.5 gms.
Oxygen absorption as determined in Respiration Experiment ..... 779.9 gms.
Difference ..... 48.4 gms.

That Pettenkofer and Voit were not far from correct in concluding that the fasting organism burns protein and

fat is seen in the successful outcome of this comparison.

It should be realized that Voit was the first to be concerned with the relative amounts of the materials oxidized by the organism. He recognized that fat in excess of the requirement is stored in the body and that more carbohydrate than fat is required to supply a given amount of energy. Voit, influenced by his teacher Liebig, originally believed, as he had been taught, that oxygen caused the destruction of fat and carbohydrate while muscular work was the cause of protein destruction. His own work however made it clear to him that neither of these generalizations could be correct. He found that muscular work did not increase the protein metabolism either of the dog or of man. He further realized that the oxygen supply does not determine the rate of oxidation in the animal organism but that this rate is inherent in the living tissue itself. These two conclusions are basic in the development of our understanding of nutrition.

The work of Voit was continued by his pupils Atwater, Rubner, and Lusk. An idea earlier put forth by Liebig was familiar to Voit and Rubner—i.e., that the organism did not oxidize carbon and hydrogen but burned directly carbohydrate, fat and protein. There is an important difference in the theoretical heat which would be obtained if the carbon and hydrogen of glucose, for example were oxidized to carbon dioxide and water, and the heat actually obtained when the same amount of glucose is burned in the calorimeter. Rubner found that one gram of glucose

burned in the bomb calorimeter of Berthelot yields 3.75 calories. If now the calories are calculated which would be produced when the carbon and hydrogen contained in one gram of glucose are oxidized to carbon dioxide and water, this important difference will be evident. If the carbon and hydrogen be oxidized to carbon dioxide and water 5.5 calories of heat would be produced. Why is it then that only 3.75 calories result when glucose containing this amount of carbon and hydrogen is burned in the calorimeter? Because both the carbon and hydrogen exist in the carbohydrate molecule in the partly oxidized state. This conception obviously holds as well for protein and fat. Rubner took it upon himself to determine the heat value to the organism of the energy yielding foodstuffs.

Since the end products of fat and carbohydrate oxidation were the same when they were burned in the body and in the calorimeter, he knew that heat resulting from oxidation was the same in both cases. Consequently he made a large series of determinations in the bomb calorimeter of various carbohydrate and fats, and proposed the following calorific values for the mixtures of carbohydrates and fats found in the average diet, carbohydrate 4.1 calories and fat 9.3 calories.

In the case of protein the situation was complicated. In the calorimeter protein may be oxidized to carbon dioxide and water and oxides of nitrogen. In the animal organism the oxidation results in the formation of carbon dioxide, water and other nitrogenous substances, chief

among which is urea. It had been the custom up to this time to subtract from the heat value of protein, determined in the calorimeter—the heat value of urea also determined in the calorimeter. Rubner perceived a fallacy in this reasoning. Urea is not the only excretory product containing nitrogen. Energy originally present in the ingested protein is also lost to the body when amino acids, creatinine and uric acid are excreted in the urine. It became clear to him that not the energy value of urea must be subtracted from the energy value of the protein but the heat value of the excreta themselves if one is to determine the energy of the protein which is available to the organism. He determined the available energy of protein in the following way. He burned 100 grams of protein from muscle in the calorimeter and obtained 534.5 calories. When 100 grams of this same type of material were fed to a dog, 2.746 grams of organic matter appeared as feces and had a heat value determined in the calorimeter of 6.127 calories per gram. Hence 16.83 calories were lost in this way. Furthermore, there were excreted in the urine 15.16 grams of nitrogen. The dried urine had a heat value of 7.46 calories for every gram of nitrogen present. 112.94 calories were lost in this way.

The energy obtainable by the organism from protein is the difference between the total energy of the protein and the energy wasted in the excreta. Hence 100 grams of protein yields 404.73 calories to the body. Therefore,

every gram of protein has a physiological heat value of 4.04 calories.

From the above figures Rubner also calculated the calories of heat produced by the oxidation of protein expressed per gram of excretory nitrogen. 100 grams of protein yielded 404.73 calories and the excreta contained 15.4 grams of nitrogen. Therefore every gram of nitrogen represents the production of 26.4 calories. Thus the calories derived from protein are calculated from the excretory nitrogen.

As a result of further experiments Rubner placed the average calorific value of protein at 4.1 calories.

Sherman has modified this value as well as those for carbohydrate and fat to allow for less complete absorption when the ordinary mixed diet is fed. The standard values have become carbohydrate 4.0, fat 9.0 and protein, 4.0.

With his knowledge of the calorific value of foods at hand, Rubner computed the older experiments in the literature, including the classic one of Pettenkofer and Voit, in which a fasting man burned 71 grams of protein and 222 of fat. According to Rubner's calculation he produced 2374 calories.[8]

In this information he saw a certain amount of confirmation supporting his hypothesis that the warm blooded animal dissipates heat in proportion to its surface, as is

[8] Rubner used the calorific value of 4.0 for protein and 9.42 for fat, the value of pig's fat.

done by the cooling ball, in accordance with Newton's Law of cooling. Aware that these data were not good enough to form a basis of a generalization in this matter he devised a machine which for the first time made it possible to measure simultaneously the heat given off by an animal as well as the oxygen which was absorbed and the carbon dioxide output. Since it was generally believed now that the animal heat resulted entirely from the oxidation of protein, carbohydrate and fat, and that the amount of oxygen absorbed and the carbon dioxide output was dependent on the amount and proportion of these materials, he calculated the heat production from the respiratory exchange. At the same time he measured the actual heat elimination of the animal.

Those who have studied the career of Rubner realize that his hope was to reduce the processes of life to the laws of physics insofar as this was permissible. He accordingly seized the opportunity afforded by his new apparatus to convince himself that the law of the Conservation of Energy—enunciated in 1845 by Mayer and in 1847 by Helmholz held completely for the animal organism.

The proof lay in the establishment of the fact that heat production equals heat elimination. He found in a typical experiment that a fasting dog eliminated 1305 calories and during the same period his heat production was 1296 calories. The discovery that life is also subservient to the law of the conservation of energy is one of the most im-

portant contributions to general knowledge, since it furnishes a solid foundation upon which to erect the study of life, for it is through energy that life relates itself to its universe.

For the special workers in the field of Nutrition the knowledge that heat production as well as heat elimination is a measure of energy transformations has had far reaching results.

Rubner's own studies with his calorimeter convinced him that a definite relationship exists between the heat production of an animal and its surface area.

The increase in heat elimination following the ingestion of food, which had been observed by Lavoisier and successive workers, was studied more carefully by Rubner. He found that this increase was much greater with protein than with carbohydrate and fat. He termed this phenomenon the Specific Dynamic Action.

Contemporary with Rubner was W. O. Atwater (1844-1907), whose name should mean much to every American, since he was the first in this country to apply modern methods of analysis to foods, and to introduce the calorimeter into this country.

Atwater was a pupil of Samuel W. Johnson of Yale. He received his Ph.D. in 1869 as a result of the first analysis of maize by modern methods. Through Johnson the Connecticut legislature had been induced to establish at Middletown the first State Agricultural Experiment Station, for the purpose of "Promoting Agricul-

ture by scientific investigation and experiment." Atwater was placed in charge. In 1888 he founded and became chief of the Office of Experiment Stations, the United States Department of Agriculture. The year before this event Atwater spent some time in Voit's laboratory with Rubner, where he had his introduction to calorimetry. Shortly after his return to this country, he with the aid of the physicist Rosa, began the construction of the first calorimeter, capable of dealing with the energy exchange in man. This calorimeter was under construction from 1892-1897 and the expense of its construction was largely defrayed by the United States Government. In 1899 Atwater with Bryant completed and published his tables of the composition of a very large number of food materials. These tables have become the standard ones for the calculation of the composition of diets throughout the world. This tremendous piece of work was done so carefully, that later work has only supplemented it. In 1896, Atwater was joined by Francis G. Benedict (1870-) a young chemist who had just received his Ph.D. at Heidelberg. The calorimeter which had just been completed was not equipped for the measurement of oxygen absorption. Oxygen had to be determined by difference as had been done earlier by Pettenkofer and Voit. Atwater realized the value of the direct determination and succeeded in obtaining funds from the Carnegie Institution of Washington for this important addition.

Because of an incapacitating illness Atwater was unable

to carry on the work and Benedict succeeded in devising the required addition. The resulting calorimeter (The Atwater-Benedict) combined for the first time the measurement of heat production, by calculation from the respiratory exchange with the simultaneous determination of heat elimination, in the case of man. In 1907 Benedict was chosen Director of the Nutrition Laboratory of the Carnegie Institution located in Boston. From this laboratory a vast amount of quantitative statistical work has emanated. The study of a fasting man covering a period of 31 days is a model of completion and accuracy in addition to being a source of most valuable information. An important outcome of this study was the recognition that fasting is accompanied by a lowering of the rate of heat production. A subsequent study during the World War by Benedict showed that the same effect results from undernutrition.

Shortly after Atwater's return to this country another American, Graham Lusk (1866-) came to the laboratory of Carl Voit, where he worked two years, in close association with Rubner and Voit. On his return to this country, he spent a few years at Yale where he began his work on intermediary metabolism of the three food stuffs. His productive interest in this field has continued throughout his career. Since 1909 he has been Professor of Physiology at Cornell Medical College. Here he built a small respiration calorimeter for use with dogs and babies. Rubner had already observed what he himself named the

Specific Dynamic Action of foods. Lusk now undertook a quantitative study of these phenomena. Lusk up to date has been the great American leader in this field. Further his book the "Science of Nutrition" is an exhaustive compilation. His enthusiasm has been behind the increasing wave of effort directed toward the scientific study of nutrition. To him was due the construction of the Russel Sage calorimeter in Bellevue Hospital in New York City. E. F. DuBois (1882-) inspired by him has given us much important knowledge gained by the use of this calorimeter. Together with his brother Delafield, he devised an accurate method for the measurement of surface area of man, which they then expressed in a simple height-weight relationship. With the aid of this formula Rubner's Law of Surface Area has been confirmed over and over again. With Aub he formulated a series of normal standards for Basal Metabolism. The mechanism of fever has been clarified, by his study of the interplay between heat production and heat elimination.

As Lusk has pointed out, as late as 1912 our European colleagues emphasized the striking dearth of scientific clinical medicine in this great land where other fields of science were contributing so largely to the world's benefit. Then abruptly, as it were, the effect of the knowledge of nutrition acquired during the preceding decades began to be felt in clinical fields. Means shortly thereafter was demonstrating the clinical value of the determination of the metabolic rate in thyroid diseases. Coleman with

DuBois was showing the increased need for energy, in typhoid fever. Later McCann, studying tuberculosis by the use of these methods was able to show that a low protein, low carbohydrate, high fat maintenance diet reduced the ventilation of the lungs to the lowest level.

Boothby was also recording variations in metabolic rate in a large number of patients. His statistical reports are of great clinical value. He first demonstrated the striking calorigenic value of thyroxin.

Later Benedict and Talbot obtained a statement of the metabolic rate in infants and children, which has become standard.

In a still broader way it must be realized that such prevalent conditions as obesity and undernutrition can be successfully studied and controlled by basing the investigation on the extent of energy transformations in such individuals. Furthermore, the striking growth of practical dietetics in America owes part of its success to the work of Atwater and to a group of clinicians of the type exemplified above.

In conclusion it should not be forgotten that the science of nutrition in its phases other than energy relationships, owes its rapid advance to the work of such men as Hopkins, Eijkman, Hölst, Krogh, Abderhalden, abroad, and McCollum, Mendel, Sherman, and Whipple in this country.

CHAPTER III

THE PRESENT DAY METHODS OF MEASURING ENERGY TRANSFORMATIONS

THE CONCEPTION has been developed that the living organism is a machine which takes in potential energy from the world outside, converts it into kinetic energy, according to its needs and returns to the universe again, all of this energy, in part converted to mechanical work and the rest dissipated as heat. It was also pointed out that the initial step in this process is the conversion of potential energy into heat by oxidation. What therefore was obviously needed, to deal quantitatively with this problem was a measure of heat production. On the other hand, since all of the energy leaves the body in the form of heat or its equivalent in mechanical work, an apparatus suitable for the measurement of the outgoing heat (in the absence of work) also offers an appropriate method for measuring energy exchange.

In order to get a clear idea of these exchanges of energy, it is necessary to become familiar with the principles underlying their measurement by both methods.

Determination of Heat Production.

The heat production is always determined by calculation from the oxygen absorption and carbon dioxide

elimination. (Indirect Calorimetry.) It is first necessary to get a quantitative conception of the amount of heat liberated as the result of the oxidation of food materials. This may be expressed in terms of oxygen used. These relationships may be brought out by considering the simplest of all food stuffs, i.e. glucose. When glucose is oxidized it yields 3.74 calories. It is possible to calculate the volume of oxygen which must be added to a gram molecule to complete its oxidation. Thus $C_6H_{12}O_6 + 6O_2 = 6CO_2 + 6H_2O + 673.2$ calories.

Therefore, 180 grams of glucose requires for its oxidation 192 grams (134.36 liters)[4] with the production of 673.2 calories. One may calculate that every liter of oxygen used in the oxidation of glucose liberates 5.011 $\left(\frac{673.2}{134.36}\right)$ calories. The amount of heat liberated per liter of oxygen is termed the calorific value of oxygen. If in the same way, the calorific value of oxygen be determined when starch ($C_6H_{10}O_5$) is oxidized—5.065 is obtained. The calorific value assigned to oxygen for the average mixture of carbohydrates in the diet is 5.047.

Thus it is clear that if the organism derived all its energy from carbohydrate one could calculate the heat production from the number of liters of oxygen absorbed. But the situation is not as simple as this, since the heat value of oxygen is not the same for fat and protein as it

[4] 1 Gram of oxygen occupies a volume of 0.6997 liters at 0°C and 760 mm.

is for carbohydrate. The calorific value of a liter of oxygen for the usual mixture of fats in the diet is 4.686. It becomes necessary then to know the nature of a metabolic mixture before one can calculate the heat production from the oxygen absorbed. This information may be obtained by also recording the respiratory carbon dioxide and the nitrogen excretion. The carbon dioxide value is significant since the oxidation of carbohydrate yields more carbon dioxide per gram molecule than does the oxidation of fat. Conditions are such that in the case of carbohydrate the volume of carbon dioxide produced is exactly equal to the volume of oxygen absorbed,[5] where as for fat only seven parts of carbon dioxide are yielded as the result of the absorption of ten parts of oxygen. Hence, when the ratio of these two gases is unity, carbohydrate alone must have been combusted. On the other hand, if the gaseous exchange for the fat is examined by dividing the volume of carbon dioxide by the volume of the required oxygen, a value of only 0.70 is obtained.[6] If the energy for any given

[5] The above becomes evident when the chemical equation for the oxidation of glucose is examined.

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$

According to Avogradro's hypothesis the same number of molecules of all gases under standard conditions of temperature and pressure occupy equal volumes. Therefore the volumes occupied by six molecules of carbon dioxide and six molecules of oxygen, are equal.

[6] $2(C_{51}H_{98}O_6) + 145O_2 = 102CO_2 + 92H_2O.$

$$\frac{102}{145} = .703$$

period were derived solely from a mixture of carbohydrate and fat, this fraction, called the Respiratory Quotient, which is obtained by dividing the carbon dioxide given off by the oxygen absorbed, expressed in volumes, would indicate the relative amounts of the two substances oxidized. Thus a value, midway between the respiratory quotient of fat and carbohydrate, namely 0.85 would mean that half of the calories came from each. Consequently, the calorific value of a liter of oxygen would also be midway between that for pure carbohydrate and pure fat. This value is 4.866. Under these conditions the organism would have a heat production of 4.866 calories for every liter of oxygen taken in by it.

If on the other hand, the oxygen absorption and carbon dioxide output yielded a respiratory quotient of 0.75, resulting from the oxidation of carbohydrate and fat alone it would be possible to calculate the calorific value of the oxygen and from this the total heat production.

At a respiratory quotient of 1.00 the calorific value of oxygen is 5.047 while at a respiratory quotient of .707 this value becomes 4.686. It is evident that a decrease in the respiratory quotient of .293 (1.00 — 0.707) results in a decrease in the calorific value of oxygen of 0.361 (5.047 — 4.686). Consequently a shift in the respiratory quotient of .01 will effect the calorific value of oxygen to the extent of .0123 calories. Therefore, an increase in respiratory quotient from .707 to .750, that is a shift of .043, will increase the calorific value of oxy-

gen by .053 (.0123 × 4.3) giving the calorific value of 4.739 for this quotient of 0.75.

When the respiratory quotient is .707, it implies the oxidation of fat alone, that is 100 percent of the calories are derived from fat. An increase of .293 in the quotient, results in the quotient of 1.00, which means 100 percent of the calories are derived from carbohydrate. A quotient at any intermediate point means something less than 100 percent of the calories derived from fat and the remainder coming from carbohydrate. We may then calculate the decrease in the percentage of calories from fat for every increase of .01 in the respiratory quotient. It is 3.413 percent. Therefore, an increase in quotient to .75 indicates that 14.7 percent (3.14 × 4.3) of the calories were not derived from fat. Hence 85.3 percent of the calories were derived from fat and 14.7 percent from carbohydrate. With this information at hand, the oxygen absorbed multiplied by the calorific value of oxygen 4.739 would give the total heat production. If it were 1000 calories 853 would have resulted from the oxidation of fat and 147 from that of carbohydrate. The amount of materials oxidized would accordingly have been 95 grams of fat and 37 grams of carbohydrate.

But in fact the organism is not restricted to carbohydrate and fat as sources of energy. It also oxidizes protein. Therefore there are three factors which determine the amount of oxygen which the organism requires and the calorific value of that oxygen. If we can subtract

from the total oxygen absorption and the total carbon dioxide output, that attributable to protein,[7] we can then calculate, as above the calories produced by the oxidation of fat and carbohydrate.

Protein can be dealt with in terms of urinary nitrogen. It has been found that for every gram of urinary nitrogen 5.94 liters of oxygen and 4.76 liters of carbon dioxide have taken part in the respiratory metabolism of protein. Likewise every gram of urinary nitrogen represents the production of 26.51 calories, liberated by the oxidation of protein.[8]

[7] $\frac{\text{Total } CO_2 - \text{Protein } CO_2}{\text{Total } O_2 - \text{Protein } O_2} = \text{Non Protein Respiratory Quotient}$

[8] These numerical relationships are derived as follows: Loewy found the elementary composition of 100 grams of meat protein to be:

C	H	O	N	S
52.38	7.27	22.68	16.65	1.02

When this amount of protein was fed there were eliminated in the urine and feces, 10.877 grams of carbon, 2.875 grams of hydrogen and 14.988 grams of oxygen. It was necessary then to remove the remainder of the carbon hydrogen and oxygen by means of the respiratory mechanism, viz 41.5 grams carbon, 4.40 grams of hydrogen and 7.69 grams of oxygen. The amount of oxygen required to oxidize the carbon to carbon dioxide and the hydrogen to water, as well as the resulting carbon dioxide may now be calculated. Since a gram molecule of carbon requires a gram molecule of oxygen to form a gram molecule of carbon dioxide (i.e., 12 grams of carbon unite with 32 grams of oxygen to form 44 grams of carbon dioxide 110.3 grams of oxygen will be required to oxidize 41.5 grams of carbon and 151.9 grams of carbon dioxide will be formed.) By the same reasoning 35.2 grams of oxygen are necessary to oxidize 4.40 grams of hydrogen to water. The total oxygen requirement would then be 145.2 grams. But the 100 grams of protein contained 7.69 of oxygen which were not eliminated in the urine and feces. Therefore

If then the appropriate values for oxygen and carbon dioxide attributable to the metabolism of protein be subtracted from the total volumes of these gases the non-protein respiratory quotient may be obtained. The calories resulting from the oxidation of carbohydrate and fat may then be calculated as well as the proportion of calories derived from each.[9] To obtain the total heat production it is necessary to add to the calories derived from fat and carbohydrate 26.51 calories for every gram of urinary nitrogen excreted.

Finally, it is apparent from the data, that a simple

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the oxygen to be obtained from the atmosphere for the completion of the oxidative processes, would be 145.2 grams minus 7.69 grams or 137.5 grams.

From this same 100 grams of protein there were excreted through the urine 16.28 grams of nitrogen. Accordingly $\frac{137.5}{16.28} = 8.49$ grams is the amount of oxygen per gram of urinary nitrogen absorbed to complete the oxidation of the protein. Similarly $\frac{151.9}{16.28} = 9.35$ grams of carbon dioxide were eliminated through the respiration as a result of the oxidation of 100 grams of protein. Since 1 gram of oxygen occupies a volume of 0.6998 liters and 1 gram of carbon dioxide a volume of 0.5094 liters at 0°C and 760 mm. pressure, it will be seen that for the excretion of every gram of urinary nitrogen there were absorbed 5.94 liters of oxygen and were expired 4.76 liters of carbon dioxide.

Loewy likewise found from his analytical data that per gram of urinary nitrogen 26.5 calories resulted from the oxidation of protein.

[9] This information has been tabulated by Zuntz and Schumburg for every non-protein-respiratory quotient. Their original values have been modified slightly by Lusk and are given in his book, "The Science of Nutrition." 4th Edition, 1928, W. B. Saunders Co.

calculation will yield the actual amount of fat, carbohydrate and protein which were oxidized.[10]

[10] A complete example of the calculation of the heat production of a normal subject in the basal state follows:
Subject: Male
Height 167 cm.
Body Surface: 172 square meters
Age: 32
Weight 64 kg.
Oxygen absorbed = 13.48 liters per hour
Carbon Dioxide eliminated = 11.12 liters per hour
Urinary Nitrogen = 0.2 grams per hour

$$\text{Total Respiratory Quotient} = \frac{11.12}{13.48} = 0.825$$

Calculation of the non-protein respiratory quotient—1 gram of urinary nitrogen represents the absorption of 5.94 liters of oxygen and the elimination of 4.76 liters of carbon dioxide. Therefore, .2 grams nitrogen $\times$ 5.94 = 1.188 liters oxygen.

.2 grams Nitrogen $\times$ 4.76 = 0.952 liters carbon dioxide. Total oxygen absorbed minus oxygen assigned to protein divided by the total carbon dioxide eliminated minus that assigned to protein gives the non-protein respiratory quotient.

Therefore: $\frac{11.12 - .95}{13.48 - 1.19} = \frac{10.17}{12.29} = .819$ non-protein R. Q. At a respiratory quotient of .82 the calorific value of one liter of oxygen is 4.825. Therefore: 12.29 liters of oxygen $\times$ 4.825 = 59.3 calories per hour which resulted from the oxidation of carbohydrate and fat. Urinary nitrogen $\times$ 26.51 gives the calories derived from protein. Thus, .2 $\times$ 26.51 = 5.3 calories per hour from protein.
Total Calories per hour = 59.3 + 5.3 = 64.6
Calories per 24 hours 64.6 $\times$ 24 = 1550
Calories per hour per square meter = 37.5.
The normal rate of heat production for this subject is according to Russel Sage Standards 39.5 calories per hour per square meter. This subject then has a basal metabolic rate five percent below the normal average.

From this same information the total calories may be apportioned to the three food stuffs.
Protein furnished 127 calories
When the non-protein respiratory quotient is .82, 40.3 percent of

Determination of Heat Elimination.

The amount of heat lost by a subject is measured directly by means of a calorimeter. The principle underlying the use of this apparatus is exceedingly simple. Since it is well known that heat is dissipated by the organism through (1) Radiation and Conduction, and (2) Vaporization of water, the apparatus is designed to collect both fractions. It consists of a well insulated box, so constructed that heat passes in neither direction. The box is provided with a coiled pipe, attached to the ceiling through which a measurable amount of water flows. The temperature of the water as it enters and leaves the chamber is recorded. The heat radiated and conducted away from the subject is absorbed by the water. The amount of heat lost by the subject in this way is calculated from the amount of water, flowing through the coils per unit of time and its increase in temperature.

The remainder of the heat eliminated by the subject, that removed by the vaporization of water, is determined

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the non-protein calories come from carbohydrate and 59.7 percent from fat. Therefore:
$1423 \times 40.3 = 573$ calories from carbohydrate
$1423 - 573 = 850$ calories from fat
Finally the actual amount of these materials oxidized were:
$.2 \times 6.25 \times 24 = 30$ grams Protein

$\frac{573}{4} = 144$ grams Carbohydrate

$\frac{850}{9} = 94$ grams Fat.

by collecting in sulfuric acid all the water vapor given off through the skin and lungs. Every gram of water thus removed carries with it .58 calories. By means of a blower the water laden air of the box is pushed outward and made to pass through sulfuric acid. Since it is necessary to remove the carbon dioxide from the box and to maintain a constant supply of oxygen this blower system is so arranged that the oxygen intake and carbon dioxide excretion can be determined quantitatively. It is obvious that from this data, heat production and heat elimination can be determined simultaneously.

Calorimetry and the Transformations of Energy.

Calorimetry is carried out in order to measure the extent of the transformation of energy by the living organism. Indirect calorimetry which measures heat production is always a true measure of total transformation. Phrased otherwise, it is a true statement of the amount of potential energy that has been converted into kinetic energy. When the subject is resting quietly, and when his internal temperature is constant, all of this kinetic energy leaves as heat, and consequently the heat elimination is as great as the heat production. But if the internal temperature of the subject rises during the period a corresponding amount of heat has been stored in the body, so that now the heat elimination is less than the heat production by the amount stored. Likewise, the mechanism is reversed when the internal temperature falls. Further,

when work is performed, some of the potential energy is changed into motion instead of heat and again the heat elimination is correspondingly less than the heat production. The respiration calorimeter is then evidently an apparatus which permits the comparison of heat production with heat elimination under divers conditions.

CHAPTER IV

ENERGY TRANSFORMATIONS UNDER VARIOUS CONDITIONS

After it had been learned that one could accurately measure energy transformations, it became highly desirable to state the magnitude of these processes under standardized conditions.

Surface Area.

Rubner, it will be recalled had pointed out, that a relationship existed between the heat production of an animal in a resting, fasting state and its surface area, rather than between the former and its weight. This fact in quantitative form has been confirmed by a number of observers. E. Voit obtained the following results:

Subject	*Weight in Kilogram*	*Calories Produced Per Kilogram*	*Per Square Meter*
Horse	441	11.3	948
Pig	128	19.1	1078
Man	64.3	32.1	1042
Dog	15.2	51.5	1039
Rabbit	2.3	75.1	776
Goose	3.5	66.7	969
Fowl	2.0	71.0	943
Mouse	0.018	2.12	1188

Strouse, Wang, and Dye compared the heat production of women, whose weights varied from 41.6 to 140 kilograms. The accompanying table again shows beauti-

fully the relationship between surface area and heat production.

Subject	*Heat Production Calories Per Kilo*	*Per 24 hrs. Calories Per Sq. M.*
Normal	26.2	926
Underweight	30.4	917
Overweight	15.1	922

It is clear from these few examples, that there is a striking uniformity in the amount of heat produced or dissipated per unit of body surface, whereas no simple relationship exists between energy transformations and body weight. Since warm blooded organisms of vastly different sizes and shapes, under the same conditions do produce the same amount of heat per unit of surface area, it may perhaps be true that normally there exists a quantitative relationship between the mass of active protoplasm and the extent of the surface area. It is seemingly also true that weight is not a measure of the amount of living active protoplasm. For example, a normal individual who doubles his weight by the addition of fat does not increase his heat production one hundred percent but only to the extent of his relatively small increase in surface area.

Though this relationship unquestionably exists it is not to be interpreted as one of cause and effect. There is no reason for believing that heat production is determined by the surface area. Its cause must lie in some inherent quality of the protoplasm. That this is true is borne out

by following the heat production from infancy to old age. When the heat production per unit of surface area is examined during this cycle, it is found that the peak occurs at the time of puberty and that thereafter there is a slow progressive fall, even though there is a further increase in surface area. Likewise, it is true that women whose surface area is the same as that of men of the same age produce distinctly less heat under the same conditions.

Again the previously normal individual who extends his surface by the acquisition of edema fluid continues to transform energy at the same rate as before. His increase in surface has not been accompanied by an increase in heat production.

In spite of these minor variations the law of the surface area as originally enunciated by Rubner, is supported by a mass of incontrovertible evidence.

Basal Metabolism.

In order to compare the rate of energy transformation in different individuals, it is necessary to put them all under the same conditions. The subject must have been without food for fourteen or more hours, at complete muscular rest during the determination and for at least half an hour before it. He must be mentally and physically comfortable and his body temperature must be normal. When these conditions are in effect, the subject is in the basal state, and his heat production is called the Basal Metabolism. The Basal Metabolism is then a measure

of energy transformations under certain standard conditions. Its value lies in the fact that heat production in the basal state is uniform. It is very nearly the same for all individuals of the same age, sex, and surface area.

To make the comparison between individuals feasible, the heat production per unit of surface area for a given period of time, conveniently an hour, is dealt with and is called the Basal Metabolic Rate. This basal rate of heat production has become a standard value for investigators as well as for clinicians. It should be pointed out that this is not the minimum heat production but one that can be obtained with great regularity and convenience. The recognition of the constancy of the basal metabolism has formed the basis of its wide application in clinical medicine. The physiological factors which influence it have been subjected to careful statistical investigation and standards for all ages and both sexes have been established. A satisfactory formula has been devised for the determination of surface area.[11] It is at present possible to predict the normal basal heat production of any given individual.

Why should there be a fixed rate of heat production for all warm blooded animals? The thyroid gland is concerned with the maintenance of metabolic rate, for when the gland is removed a very permanent fall results.

[11] For a complete discussion of these matters, the reader is referred to DuBois, E. F. "Basal Metabolism in Health and Disease." 2nd Edition, Lee & Febiger, Phila. 1927.

The heat production may be restored to its original level by the administration of thyroxin or thyroid gland. Further the rate may be strikingly increased above the normal by the administration of thyroxin. But in addition to the secretion of the thyroid gland, there must exist a certain something which causes the protoplasm to carry on oxidation and maintain body heat. In fact, isolated cells in the proper medium grow and respire indefinitely in the presence of food and oxygen. The thyroid gland may then be the regulator of an inherent process.

Variations in Basal Metabolic Rate.

The basal metabolic rate may be set at a lower or higher level, by disease. The well known elevation of metabolic rate characteristic of hyperthyroidism is an example of this phenomenon. In this case, conditions are so altered that the cells automatically maintain a higher rate of oxidation. In health the heat produced in the basal state is not available for the performance of mechanical work. Neither is the higher basal heat production of the hyperthyroid. In both cases there must be a production of extra heat for this purpose. In hypothyroidism on the other hand the rate of oxidation is set at a level below the normal.

The depressing effect of undernutrition on the basal metabolic rate is interesting. Individuals who are seriously underfed experience a marked fall in their funda-

mental rate of heat production. This lower rate of oxidation continues as long as the underfeeding. After the fall has occurred it may be maintained as long as the total inflow of energy does not exceed the outgo in this new state. Only when sufficient energy is added to this low diet to permit a gain in weight does the basal metabolic rate return to its original level. On the other hand, there is no satisfactory evidence that over abundance of energy in the diet will cause a new higher level of basal metabolism.

To a lesser degree the basal metabolic rate may be influenced by a few other pathological states.[12]

Heat Production Throughout the Twenty-Four Hours.

We may picture the heat production throughout the whole twenty-four hours as consisting of an inherent basal rate to which there are additions and from which one subtraction must be made. The heat production during sleep averages 10-15 percent below the basal. This sleeping rate may be thought of as the lowest level of heat production compatible with the maintenance of the vegetative life of the normal warm blooded organism. In the other direction the performance of mechanical work and the ingestion of food increases the heat production above the basal level. These two effects together, more than over-balance the depression due to sleep so that the

[12] McCann, W. S. Medicine 1924, III, 1.

twenty-four hourly heat production, even of the normal individual is always considerably greater than the basal metabolic rate.

In the performance of work there is an extra production of heat, in proportion to the amount of work done. The increase in heat production is always around four times that which theoretically is necessary to perform a given amount of work. It is well to get a concrete idea of the absolute value of this factor. Since 427 kilogram meters of work may be performed at the expense of one Calorie, it may be calculated that one Calorie would permit a man weighing 60 kilograms to lift himself twenty-three feet. Since the organism needs to release four Calories of heat in order that he may convert one to work, the above amount of work may be thought of as being accomplished at the expense of one gram of glucose. In other words, roughly, the energy necessary to climb two ordinary flights of stairs, may be obtained from a single gram of carbohydrate.

The average man who weighs sixty kilograms produces 3000 Calories of heat per day. Some 1400 of these make up the basal requirement while roughly another hundred may be accounted for by the extra heat production resulting from the ingestion of food. The remaining 1500 Calories must have been produced to make possible the performance of work. The amount he is thus enabled to do, equals that required for him to climb a mountain a mile and a half high.

It has already been pointed out that the ingestion of food increases the heat production. Lavoisier early recognized this fact. Rubner obtained quantitative records of it, while Lusk has concerned himself with the nature of this phenomenon. He has shown that there is an essential difference in the effect of protein as compared with that of carbohydrates and fat. Properly designed experiments have shown that it is not an expression of the work of the mechanism concerned with digestion and absorption, that it is not a measure of the activity of the secretory glands nor of the smooth musculature. It has to do with the intermediary metabolism of the foods. In the case of protein the response is proportional to the amount given, whereas, in the case of fat and carbohydrate this is not so. The extra heat produced from protein is not available for work. That is, an individual who ingests definite amounts of protein, and then performs a measured amount of work, will have a heat production equal to his basal plus that due to the action of the protein, plus that increment necessary for the performance of the work, in other words, there is a true summation.

On the other hand, the extra heat which results from the ingestion of carbohydrate, may be utilized for the performance of mechanical work.

In the case of protein, the increase in heat production is always observed, while the state of nutrition of the animal determines whether or not there will be any re-

sponse to the other two foods. When an animal is under-nourished, the administration of carbohydrate results in no increase in heat production. According to Lusk, the response only occurs after fat and carbohydrate when a plethora of them exists.

It is an interesting fact that some of the animo-acids produce the same response as protein, while no effect is observed with others.[13]

These factors then make up the total energy transformations of the normal individual during twenty-four hours. In order to visualize the distribution of these transformations we may apportion them for a normal man as follows:

	Cal. per 24 Hours
Basal Metabolism	1400
Food 6 percent of Basal	84
Mechanical work	1600
	3084
Sleep saves 15 percent of basal for approximately 8 hours	70
Total	3014

Since as will be seen, the effects of food and sleep balance each other, one may estimate roughly that the total energy transformations of an active individual are twice his basal calories.

The factors which normally affect the heat production have been discussed. Two special conditions occur in

[13] The most complete discussion of this complicated question may be found in Lusk's "Science of Nutrition" 4th Edition, 1928. W. B. Saunders Company, and his article in Medicine, 1922, Vol. I p. 311.

which the presence of abnormal body temperature introduces a new problem.

Fever.

In fever, the question arises, What has occurred to cause the increased body heat and how is it maintained? DuBois and his co-workers observed patients with malarial fever in the calorimeter during the course of a severe chill. The events may be seen in the following tables:

Time	*Rectal Temp. 0°C*	*Heat Production*	*Heat Elimination*
		Cal. per 24 Hours	
Before chill	37	90	70
Chill (duration 40 minutes)	39	230	80
After chill, first hour	39.5	130	90
Second hour	40	125	100

It will be noted that there was a huge increase in heat production with essentially no increase in heat elimination during the chill. The extra heat produced was consequently stored in the body, whose temperature rose two degrees. During the two hours following the chill, the heat production remained somewhat elevated, and continued to be greater than the heat elimination. Sufficient heat was thus stored in the body to raise its temperature one more degree.

Further experiments during the fall in temperature following the chill showed a reversal of the above events that is, increase in heat elimination which exceeded the heat production.

For comparison these observers also recorded the events in the case of a normal individual who voluntarily shivered for thirty-four minutes.

Time	*Temp.* °C	*Heat Production Cal. per Hour*	*Heat Elimination Cal. per Hour*
Before	36.6	70	70
Chill (duration 34 minutes)	37.0	190	140
After chill, 30 minutes	37.0	80	105
90 minutes	36.8	75	90

The increase in heat production of the normal subject as the result of voluntary shivering was of the same order of magnitude as that accompanying the malarial chill. Furthermore, the normal man was able to double his heat elimination during the period of increased heat production and so experienced only a trivial rise in body temperature, whereas, the malarial patient could not increase his elimination of heat materially during the chill. When the normal subject stopped shivering, his heat production fell abruptly and was exceeded by the elimination. The patient with malaria, however, following the chill did not experience the same degree of fall in heat production. Even more significant is the fact that he continued to eliminate less heat than he was producing for at least two hours. Evidently then, the extra heat production of a chill is easily accounted for by the muscular activity. The great difference between the phenomenon in the normal and malarial subjects is the inability of the latter to increase his heat elimination.

The abnormality in the case of disease evidently con-

sists of a disturbance of the mechanism for the elimination of heat. Thus the experimental production of fever by the injection of foreign protein is entirely analagous to that of malaria, since in both cases the mechanism of heat elimination fails.

An increase in heat production above the basal level is a feature of all fevers. DuBois has related this increase to a well known physico-chemical principle enunciated by van't Hoff, that is, that the speed of chemical reaction increases two or three times for every rise of ten degrees in temperature.

By the application of this principle, it is possible to estimate the basal metabolism of an individual with fever.

With these facts in mind one can arrive at a picture of the mechanism of fever. The elevated temperature that is a feature of disease due to micro-organisms is initiated by an effect of some product of these organisms upon that part of the central nervous system that controls the flow of blood through the skin. The dry skin is the clinical evidence that less than the usual amount of water is available for vaporization, one of the most important processes employed by the organism for the removal of heat. The moist skin, which follows the administration of the antipyretics is an interesting feature in this connection, since, it would seem as if these drugs reduce the temperature by again making it possible for the organism to rid himself of much heat by the vaporization of water.

In the experiments of DuBois it was found that the organism was prevented from eliminating sufficient heat by radiation and conduction as well as by vaporization. The relationship between these two processes was not however seriously disturbed.

This decreased ability to lose heat by vaporization and radiation results in a disproportion between heat production and elimination which inevitably causes an increase in internal temperature. According to van't Hoff's law, this increase in temperature will now establish the rate of oxidation at a higher level. As the organism recovers from the effect of the invasion by the micro-organisms, it again gains better control over the mechanism for removing the heat, rapidly as in pneumonia, or slowly as in typhoid fever, and in this way rids itself of the stored heat until it has re-established the normal temperature.

In contradistinction to fever is the condition known as hyperthermia, meaning an elevation of temperature due to some physical reaction rather than bacterial cause. This condition was unwittingly produced in Woodyatt's laboratory by the injection of hypertonic glucose solution. The intense diuresis thus set up drained away the body water and was thus productive of temperatures as high as 125°F. A similar condition occurs in the diarrhoeas of infancy. In both instances the depletion of water prevents the organism from losing sufficient heat by vaporization.

Interference with this mechanism for the removal of

heat may come about in still another way. The laborer exposed to the rays of the sun on an unusually hot humid day, produces (because of the work) a large amount of heat, to which he adds some absorbed from the sun. On the other hand, his only means of ridding his body of heat, under these conditions is by vaporizing water. The high humidity limits this process. As a result his internal temperature rises. van't Hoff's laws comes into effect and there is therefore an ever increasing rate of heat production, with no corresponding increase in heat elimination.[14]

Hibernation.

It is characteristic of the mammalia when exposed to cold to maintain their established body temperature by an increased production of heat. A few types of this class, however, exhibit a response to environmental cold that appears to be an atavism, reminiscent of their remote cold blooded ancestors. These unusual mammals, like the frog, exhibit a falling heat production and a falling internal temperature, as a reaction to the oncoming winter. Their temperature falls to a surprisingly low level and records of O°C are available. The great fall in the oxidative processes presumably is in accord with the law of van't Hoff, and is so marked that it is accompanied by the lethargy of the cold blooded animal.

[14] This discussion of the disturbances in body temperature will be appreciated better after the reader has familiarized himself with Chapters V and VI.

Here, the striking change is the fall in heat production. Students of this subject have calculated that food equivalent to the requirement for a single day in the waking state is sufficient to maintain the animal during hibernation for fifteen days.

PART II

THE INSENSIBLE LOSS OF WEIGHT

CHAPTER V

THE NATURE OF THE INSENSIBLE LOSS OF WEIGHT

THE INDIVIDUAL who neither adds to his weight by the ingestion of food and water nor diminishes it by voiding urine or stool, still loses weight continuously. This comes about because he excretes carbon dioxide and water vapor. But the reduction in body weight caused by the outward passage of these two, is in part compensated for by the weight of the oxygen simultaneously added to the body. This relationship may be expressed mathematically in grams as follows:

Insensible Loss of Weight = $H_2O + CO_2 - O_2$.

Benedict determined the insensible loss of weight and the heat production in a number of subjects whose metabolic rates varied widely, and found that the insensible loss and the heat production are proportional in the basal state. He was accordingly able to predict the heat production from a knowledge of the hourly insensible loss of weight. The accompanying table is taken from his publication.[15] (For Table, consult page 56.)

We have here a third method for the measurement of energy transformations. This method gives precisely the same information that is obtained when heat loss

[15] Benedict and Root, Arch. Int. Med., 1926, vol. 38, p. 1.

Twenty-four Hour Heat Production Predicted from the Hourly Insensible Loss of Weight

Insensible Loss Grams	*Predicted Heat Calories*	*Insensible Loss Grams*	*Predicted Heat Calories*
14	900	38	1,655
16	965	40	1,715
18	1,028	42	1,775
20	1,090	44	1,840
22	1,155	46	1,900
24	1,215	48	1,965
26	1,280	50	2,025
28	1,345	52	2,085
30	1,405	54	2,145
32	1,470	56	2,210
34	1,530	58	2,275
36	1,590		

is measured by the calorimeter. Why does this quantitative relationship hold?

It will be recalled that some of the heat lost by the individual in the calorimeter was accomplished by converting liquid water into water vapor. The physicist recognizes that this process requires heat. A definite amount of heat (0.58 calories per gram of water) leaves the body because it has been stored in the vapor. This heat loss, calculated from the water vapor given off (collected in sulphuric acid and weighed) has been found to be close to twenty-five percent of the total heat lost by the subject in the calorimeter. If, instead of being in a calorimeter, the subject were suspended from one arm of an analytical balance, he would still continue to get rid of heat by vaporizing water.

The insensible loss of weight (recorded by the balance) is very largely due to the progressive loss of water from the skin and lungs; hence, the insensible loss of weight must at least be an approximate measure of the water vapor. If it is also true that the organism (in the basal state) loses a fixed proportion of its heat by vaporizing water, it necessarily follows that the insensible loss of weight and the calories of heat eliminated, rise and fall together.

Is there any constancy between the total heat elimination and the fraction of it removed by vaporization of water? It has already been pointed out that subjects in the calorimeter rid themselves of about twenty-five per cent of their heat by that process. This question has been examined by us for subjects suspended from the balance. We obtained the insensible loss of weight together with the oxygen absorption and the carbon dioxide output. With these three values at hand, the weight of the water vapor was obtained by the use of the equation already mentioned, viz:

Insensible Loss of Weight = $H_2O + CO_2 - O_2$

The heat equivalent of the water vapor was then obtained by multiplying it by 0.58. The calories removed from the body in that way were compared with the total heat production, calculated in the standard way from the respiratory exchange.

An example will make these matters clearer. A man lost insensibly 28.9 grams per hour. He absorbed 17.06

Relation Between Heat Lost by Vaporization of Water and Total Loss of Heat in the Basal State.

Insensible Loss	*Carbon Dioxide*	*Oxygen*	*Insensible Water*	*Total Heat*		*Heat Lost by Vaporization*	
				Gasometric	*Gravimetric*		
gm. per hour	gm. per hour	gm. per hour	gm. per hour	cal. per 24 hrs.	cal. per 24 hrs.	cal. per 24 hrs.	percent
28.9	19.16	17.06	26.8	1382	1372	373	27
26.6	17.83	16.29	25.1	1312	1300	349	27
28.3	17.53	16.90	27.7	1347	1354	386	28
23.9	16.36	15.54	24.1	1243	1242	336	27
27.1	17.34	16.62	26.4	1326	1315	368	28
29.2	17.59	17.28	28.9	1372	1382	402	28
26.7	17.31	15.62	25.2	1285	1301	351	27
25.3	16.38	15.45	24.4	1237	1257	340	27
27.5	17.11	16.44	26.8	1312	1327	373	28

grams of oxygen and gave out 19.16 grams of carbon dioxide per hour. Hence:

$28.9 = x + 19.16 - 17.06$

$x = 26.8$. Water vapor in grams.

The heat removed by that amount of vapor was $26.8 \times .58 = 15.5$ calories per hour or 373 calories in twenty-four hours. The total heat production for the twenty-four hours was 1328 calories. Since the subject was in the basal state, his heat loss was equal to the heat production. Hence, 373 of the 1328 calories, eliminated in twenty-four hours, were removed by vaporization of water. In other words, the subject got rid of 27 per-cent of the heat by evaporation of water.

The accompanying table shows that in a series of determinations the subject removed a fixed proportion of the total heat eliminated by the vaporization of water.

It is accordingly true that subjects in the basal state, whether in the calorimeter or suspended from the balance, vaporize water in amounts directly proportional to the quantity of heat produced. Further, the weight of this water is at least approximately determined by recording the total insensible loss of weight, since it is made up so largely of the weight of the water vapor.

The next question to be considered is whether the water vapor maintains a constant relationship to the insensible loss of weight. Since the weight of the water vapor is fixed for any given heat elimination, the insensible loss of weight will also be fixed if a constant relationship

between the weight of the carbon dioxide excreted and that of the oxygen absorbed, be maintained. Since, however, the volume relationships of carbon dioxide and oxygen vary with the nature of the foodstuffs being oxidized, a variation in their relationship by weight is to be expected at different respiratory quotients.

Let us, by means of actual figures, see what effect variations in R. Q. will have upon the relationship of the weight of the water vapor to the total insensible loss of weight.

Consider a subject who has a basal heat elimination of 2025 calories. We have found by experiment that under basal conditions the heat lost by the vaporization of water is about 28 percent of the total heat production when the subject is suspended on the balance. Therefore, this individual with a heat production of 2025 calories lost 567 calories by the vaporization of water. This value divided by the Latent Heat of Vaporization of water at body temperature gives the amount of water vaporized,

i.e. $\frac{567 \text{ calories}}{.58} = 978 \text{ grams}$

Since this individual is in the basal state, it may be assumed that he has the usual respiratory quotient of .82. The calorific value of a liter of oxygen is 4.825 at this respiratory quotient. Therefore, in order to oxidize materials yielding 2025 calories, he must absorb $\frac{2025}{4.825} =$

419.7 liters of oxygen. Since the respiratory quotient is 0.82 the carbon dioxide given off equals $419.7 \times .82 = 344.2$ liters. Further, since one liter of oxygen weighs 1.4291 grams and one liter of carbon dioxide weighs 1.9634 grams, the weights of oxygen and carbon dioxide given off are respectively 600 grams and 676 grams.

Applying these data to the equation given above, we may calculate the total insensible loss of weight.

Insensible Loss = Water + Carbon Dioxide — Oxygen

$$x = 987 + 676 - 600$$

$$x = 1054 \text{ grams.}$$

Hence, a subject who complies with the three following conditions:

(1) Eliminates heat at the rate of 2025 calories in twenty-four hours;

(2) Removes 28 percent of this heat by means of vaporization of water;

(3) And produces this heat from a mixture whose oxidation results in a respiratory quotient of 0.82;—will lose insensibly 1054 grams in twenty-four hours. The weight of the water lost as vapor will be 92.8 percent of the total insensible loss.

Let us now see how this relationship of the weight of the water vapor and the insensible loss of weight is effected by the maximal possible variation in the respiratory quotient. It is assumed that this subject derived his 2025 calories entirely from carbohydrates. Therefore,

the respiratory quotient is 1.00 and the calorific value of one liter of oxygen 5.047. We may calculate the grams of oxygen absorbed and the carbon dioxide given off as we did above.

$$\frac{2025}{5.047} = 401.2 \text{ liters of oxygen}$$

$$\text{R. Q.} = 1.00$$

Therefore, $CO_2 = 401.2$ liters

$$401.2 \text{ liters} \times 1.9364 \text{ grams} = 788 \text{ grams } CO_2$$
$$401.2 \text{ liters} \times 1.4291 \text{ grams} = 573 \text{ grams } O_2$$

Then

$$x = 978 + 788 - 573$$
$$x = 1193 \text{ grams}$$

Hence, with no change in the conditions other than a shift in the respiratory quotient from 0.82 to 1.00, the total insensible loss of weight has increased from 1054 grams to 1193 grams. This comes about because it takes 27 fewer grams of oxygen to obtain 2025 calories from pure carbohydrate than were required to complete the oxidation of the mixture when the quotient was .82. At the same time, 112 grams more CO_2 are produced when the heat is derived solely from carbohydrate. The subject accordingly loses insensibly 112 grams more as CO_2 and adds 27 grams less as O_2. The effect upon the total insensible loss for the twenty-four hours is the sum of these values or 139 grams. Since the weight of the

vaporized water remains constant, it will in this case be only 82 percent of the total insensible loss.

If, on the other hand, we assume that the 2025 calories were derived completely from the oxidation of fat, the respiratory quotient would be 0.707 and the calorific value of one liter of oxygen, 4.686. Again we calculate the weight of oxygen absorbed and carbon dioxide given off, and find them to be 638 grams and 600 grams respectively. Applying these values to our equation, it becomes

$x = 978 + 600 - 638$

$x = 940$ grams.

When the heat is obtained solely from the combustion of fat, the oxygen requirement is so great, that it weighs more than the carbon dioxide produced. The subject must then actually add to his weight through the exchange of the respiratory gases. Since the weight of the water is the same as heretofore, the total loss of weight on the part of the subject, must be slightly less than that of the water vaporized. Accordingly, if fat alone were the source of the 2025 calories, the total insensible loss of weight for the twenty-four hours would be only 940 grams; while the corresponding insensible water would weigh 104 percent of this insensible loss.

From these calculations it is seen that, with a heat production of 2025 calories, the total insensible loss may exhibit a maximum variation of 253 grams. But since the organism usually derives energy from a mixture of the three food stuffs, and only under special conditions

from pure carbohydrate or fat, the insensible loss calculated at a respiratory quotient of .82 would be the most probable one.

The accompanying table shows the maximum variation from this common value.

Insensible Water	*Total Insensible Loss*	*Respiratory Quotient*	*Percentile Variation*
978	1193	1.00	+13
978	1054	0.82	0
978	940	0.707	—11

Since however, the respiratory quotient is usually not extremely high or low, the expected variation would be not more than five percent. In the exceptional instances when very high or low quotients occur, the observer would persumably be aware of that fact and could allow for it.

These calculations show then, that the relationship of the water vaporized to the total insensible loss of weight is, for all practical purposes, a constant when the individual is in the basal state. Evidence of the constancy of this relationship is found in the results of Benedict and Root; since to make their prediction table they actually determined the heat production and the insensible loss of weight under basal conditions and found one a linear function of the other.

This method, then is as accurate as the other methods which have been discussed for the determination of heat production in the basal state.

CHAPTER VI

ENVIRONMENT AND INSENSIBLE LOSS

IN THE PRECEDING chapter, it was shown that the insensible loss of weight is a measure of heat production in the basal state. When the term "basal state" is used, certain conditions are implied, namely, (1) fasting, (2) muscular relaxation, (3) normal body temperature, (4) comfortable environment. This last condition is of especial importance when the heat production is determined from the insensible loss of weight.

In order to deal intelligently with the environmental effect upon the insensible loss of weight it is first desirable to describe briefly the mechanism available to the organism for ridding itself of internal heat.

The fasting resting nude subject exposed to an environmental temperature of 24°C (relative humidity about 20 percent), produces heat at the basal rate. From then on increases in the temperature of the air up to 42°C or above do not increase the heat production. Since the internal temperature remains constant it is clear that the organism is able to remove this heat at the rate at which it is produced, regardless of the wide swing in environmental temperature. In the range of what might figuratively be thought of as the temperate zone, that is from about 24°C to 32°C, most of the heat is removed by

radiation and conduction aided by convection while the rest is removed by vaporizing water.[16]

At the lower temperature, (24°C) about twenty percent of the heat is lost by vaporizing water. This value mounts until at 32°C it has become about thirty percent. This shift may be explained on a purely physical basis. If the surface temperature remained constant, and the heat production constant it is apparent that heat loss by the dry method would decrease as the environmental temperature rose. Contrawise, vaporization would increase as the outer temperature rises. But, as a matter of fact the surface temperature does not remain constant under these conditions. Observations show that it rises at about half the rate of the rise in environmental temperature, thus tending to maintain the distance between the environmental and surface temperature. The increase in the temperature of the environment from 24° to 32° is accompanied by an increase in surface temperature from 30.5° to 35°. Accordingly the heat loss by the dry method diminishes as the temperature of the air increases, but the rate of diminution is modified by an increase in surface temperature. At the same time heat loss by the wet method is augmented by the increase in surface temperature as well as by the rise in environmental temperature. Thus under these basal conditions purely physical processes are

[16] In order to avoid an awkward repetition of a series of long words, the methods of losing heat will hereafter be spoken of as "the wet method" meaning loss by vaporization and "the dry method" when loss by radiation, conduction and convection is meant.

adequate to account for the manner in which heat is lost from the surface of the organism.

The amount of heat lost, however, must be equal to that produced. This is made possible by the vasomotor apparatus, which adjusts the volume flow of hot blood thru the skin to meet the conditions.

This neuro-muscular system, as is well known, reflexly increases and decreases the calibre of the blood vessels. When the environment is cold the constriction of the peripheral vessels diminishes the entrance of the hot internal blood into the skin. A hot environment produces the opposite effect. With a constant heat production and the necessity of removing the heat as it is produced, an increasing environmental temperature (within the range of 24-32°C) will require an increased exposure of the blood to the surface to accomplish this end. The vasomotor system therefore responds to the environmental temperature in such a way that it permits the circulation of the warm blood thru the skin, in amounts sufficient to rid the organism of the heat which is produced and constitutes the most important vehicle for the removal of heat. This mechanism is not concerned with the manner in which the heat is carried away. It has already been shown that the relative proportions of heat removed by the wet and dry methods can be explained by simple physical principles.

Above 32°C the environmental conditions no longer permit removal of the heat rapidly enough by the methods

just described even though the blood vessels in the skin are widely dilated. The sweat glands now begin to deliver water to the surface for vaporization. The percentage of heat removed by the latter method rapidly increases as the environmental temperature rises until all of the heat is removed by the wet method when the outer temperature is 36°C since at this point the surface temperature has also attained this same level. Clearly, when the two temperatures are the same, there is no transfer of heat by the dry method. Still higher environmental temperatures cause absorption of heat by the organism which now removes it in addition to the heat produced, solely by the wet method. The secretory activity of the sweat glands at high environmental temperature is to be regarded as a physiological factor to aid in the removal of heat.

Finally, as the environmental temperature falls below 24°C the internal temperature is maintained by an increasing heat production, since at these low temperatures in the case of the nude resting subject the minimum loss of heat from the surface is greater than the basal heat production. At 18°C only 15 percent of the heat is lost by the wet method. The surface temperature in this cold environment has fallen to 29°C. The larger difference between surface and environmental temperatures promotes radiation, but the low temperatures tend to inhibit vaporization.

Below 24°C the physical conditions allow the removal of much heat, even though the flow of blood through the

skin is minimal. Consequently more heat must be produced if the internal temperature is to be maintained.

If now the heat production of the individual is increased above the fasting level, a correspondingly increased blood flow brings more heat to the surface. Observation has shown that under these conditions the actual quantities of heat removed still equal the production; and further, that the proportions carried away by the wet and dry methods are the same as in the fasting state. It is interesting to note that when the heat production is increased, activity of the sweat glands begins at a lower temperature.

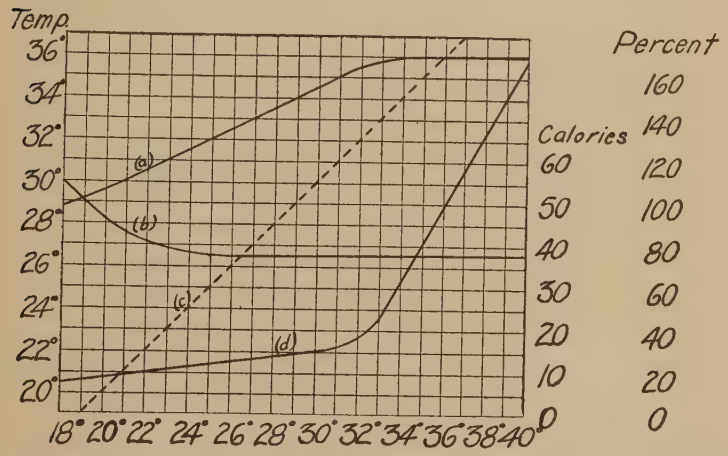

Figure I shows the effect of environmental temperature (c) on the temperature of the skin, (a) the heat production (b) and the per cent of heat lost by vaporization of water. (d) The environmental temperature is indicated by the broken line.

The humidity of the atmosphere also plays a part in the removal of heat from the body. It is well known that wet air conducts heat more efficiently than dry and also inhibits vaporization of water. The magnitude of these effects has not been sufficiently studied, but it may be stated that the ordinary range of humidity does not seriously disturb the manner of heat loss.

A third factor in the environment—air currents, must also be considered. Heat loss both by the wet and dry methods are aided by this process. But the presence of the vasomotor apparatus apparently protects the organism from excessive loss of heat due to winds by causing less blood to come to the surface of the body. This adjustment of the vasomotor apparatus may be pictured as the opposite of what occurs when extra heat is to be removed in a quiet warm atmosphere.

With this mechanism for removing heat from the body in mind one may again take up the relationship between the insensible loss of weight and heat production.

It has already been pointed out that the heat production is constant at temperatures above 24°C and that the heat lost by vaporization increases only slightly up to 32°C. Consequently, the range through which insensible loss may be used as a measure of heat production lies between 24-32°C. The actual increase in the heat loss by the wet method within this range is only ten percent. At the mid-point (28°C) twenty-seven percent of the heat is removed in this way. The extreme variation in either

direction from this mid-point is five percent. The ideal table for the prediction of the total heat production from the insensible loss of weight in the case of the nude fasting subject should be constructed from observations made at 28°C. Then the maximal error within the above mentioned range would be five percent.

The clothed subject, however, loses a little more heat by vaporization and correspondingly less by the dry method than the nude subject at any given temperature. Furthermore he adjusts the amount of clothing to the temperature of the air, thus apparently maintaining a constant relationship between the two methods of heat loss over a wide variation in temperature. The details of these relationships in the case of the clothed subject are being obtained.

All these considerations and the evidence at hand justify the statement that the insensible loss of weight of the comfortably clothed resting individual is a satisfactory method for measuring dissipation of heat.

CHAPTER VII

APPLICATIONS

A. The Total Transformation of Energy During the Twenty-four Hours

A KNOWLEDGE of the heat production of individuals who are not restricted to the basal state, not only adds to our appreciation of the life process but is also essential in the solution of certain nutritional problems. Serious difficulties stand in the way of obtaining this information by means of the calorimeter or through indirect calorimetry. The application of the new knowledge of the nature of the insensible loss of weight, seemed to us to offer a satisfactory method for obtaining the desired information. Our recent studies have convinced us that it is a simple matter to measure the loss of heat for long intervals of time, in twenty-four hourly periods. The justification of this procedure will become evident from the following discussion.

A man who leads a normal life gains and loses weight sensibly and insensibly. The sensible additions consist of food and water; the sensible losses of urine and stool. The insensible gain is the added oxygen and the insensible losses are the excreted carbon dioxide and water vapor. The weight of the sensible additions and subtractions as well as the initial and final weight of the subject are ob-

tained in the usual way. His final weight is the resultant of both types of additions and losses. If the individual were not losing or gaining insensibly, his weight at the end of the period would be the algebraic sum of his initial weight and the sensible additions and losses. Thus a subject weighed at the beginning of a period 55.97 kg. He added to his weight, food and drink weighing 2.077 kg. During the same period he decreased his weight by the loss of stool and urine weighing 1.394 kg. Had there been no insensible loss or gain, he would have weighed at the end of the period 55.975 + 2.077 — 1.394 = 56.658. But, in fact, his weight at the end of the twenty-four hour period was 55.670 kg. This difference of 988 grams is the insensible loss of weight for the twenty-four hour period. This 988 gm. as will be recalled, is the weight of the outgoing carbon dioxide and water vapor, minus the weight of the ingoing oxygen. During this period, this individual excreted 929 gm. of water vapor and 587 gm. of carbon dioxide. At the same time, he took in 528 gm. of oxygen. The algebraic expression of these items is 929 + 587 — 528 = 988 gm., which is the insensible loss of weight.

If we express this twenty-four hour insensible loss in grams per hour, the twenty-four hour heat loss may be determined by reference to Benedict's table.[17] In the case cited, the total insensible loss of 988 gm. is a loss of 41 grams per hour. The table shows that this cor-

[17] This table is reproduced in Chapter V, p. 70.

responds to a twenty-four hour output of heat of 1745 calories.

The validity of the extension of this method to states other than the basal rests on the evidence that the relationship between the total heat loss and the loss caused by the vaporization of water is again a constant. This is clear from the following table.

Relation Between Heat Lost by Vaporization of Water and Total Loss of Heat

Twenty-Four Hour State[18]

Insensible Loss	*Insensible Water*	*Total Calories*	*Percent Heat Lost by*
gm. per 24 hrs.	*gm. per 24 hrs.*	*24 Hours*	*Vaporization*
1272	1143	2121	31
1176	1132	2000	33
1200	1092	2030	31
1008	986	1813	32
986	929	1746	31
1039	981	1815	31
939	880	1688	30

B. The Metabolic Mixture

The term "metabolic mixture" is used to mean the actual amounts and kinds of materials oxidized in the body to yield the heat for any given period. Let us

[18] It will be noted that the heat lost by vaporization is 31 percent of the total twenty-four hourly amount, whereas this same subject lost in the basal state 28 percent of his heat in this way. This slight difference is probably due to the fact that the weight of the water vapor for the twenty-four hour period is obtained indirectly since the weight of the oxygen inspired and expired carbon dioxide was calculated instead of being determined directly.

begin with the fasting state. The total nitrogen output multiplied by 6.25 gives the amount of protein oxidized. The total outgoing calories minus the calories from protein, represent those which are derived from carbohydrate and fat. By means of the non-protein respiratory quotient, the proportion of the calories derived from carbohydrate and fat are obtained, and from this the actual amounts of the two oxidized. Since it is practically impossible to obtain the heat production and respiratory quotient directly over long periods of time, some other method must be employed to obtain this information.

As has been pointed out, the determination of the insensible loss is a satisfactory measure of the total heat loss for consecutive twenty-four hour periods. If the study begins after the third day of the fast, the body will have depleted its store of glycogen, and will derive its energy essentially from the oxidation of protein and fat. Hence, one needs to know only the total insensible loss and the nitrogen output to calculate the metabolic mixture.

Since it is usually desirable to study subjects who are receiving food, a plan for these conditions needs to be devised. Let us apply our procedure first to an individual receiving a sub-maintenance diet. First one must know the exact composition of the diet. This may be determined accurately enough for this purpose by calculation from the standard food tables. The total nitrogen output is used as a measure of the protein metabolized.

In the state of under-nutrition, evidence indicates that

the carbohydrate of the diet which represents a readily available form of energy, is completely oxidized; that is, none will be stored as glycogen or fat. The carbohydrate of the diet therefore, becomes the carbohydrate of the metabolic mixture except during the first day or two, when some stored glycogen may be burned. Since we now know the protein and carbohydrate of the metabolic mixture and have determined the total energy output by means of the insensible loss of weight, it is merely necessary to apportion to fat the outgoing calories not derived from protein and carbohydrate.

If, on the other hand, the subject be fed a diet which is more than equal to his maintenance requirement, and whose composition is known, we may again calculate the metabolic mixture. Since glycogen may be stored under these conditions for a day or two, the study is begun after the subject is in balance with his new diet. The calories of the metabolic mixture will, as always, equal the total outgoing calories. Therefore, the difference between the the outgoing calories and those of the diet, will be stored as fat. The metabolic mixture may then be considered to be the protein, determined from the nitrogen output, the carbohydrate of the diet, and the fat of the diet minus the fat stored.

If it were possible to feed an individual a diet which exactly met his maintenance requirement, then the metabolic mixture would equal the diet fed. Since, however, the outgoing calories vary from day to day, this can sel-

dom be the case, and hence the actual calculation of the metabolic mixture is usually necessary.

The actual figures from a period of undernutrition may be cited.

Composition of the Diet:

Protein	Fat	Carbohydrate	Calories
60 gm.	49 gm.	126 gm.	1185

(1) Nitrogen Output:

Urine = 12.11 gm.
Stool = 0.45 gm.
Total = 12.56 gm.

(2) Total Heat Loss:

Total Insensible Loss = 1,176 gm. which is equivalent to 2,000 Calories.

(3) Metabolic Mixture:

Protein = 12.56 gm. $\times$ 6.25 = 79 gm. $\times$ 4 = 316 Cal.

Carbohydrate = 126 gm. $\times$ 4 = 504 Cal.

$$\text{Fat} = \frac{2000 - (316 + 504)}{9} = 131 \text{ gm.}$$

For Comparison a period of overnutrition is reproduced below:

Composition of Diet:

Protein	Fat	Carbohydrate	Calories
63	94	309	2334

(1) Nitrogen Output:

Urine = 11.15 gm.
Stool = 1.17 gm.
Total = 12.32 gm.

(2) Total Heat Loss = 2121 Calories

(3) Metabolic Mixture:

Protein = 12.32 gm. × 6.25 = 77 gm. × 4 = 308 Calories

Carbohydrate = 309 gm. × 4 = 1236 Calories

$$\text{Fat} = \frac{2121 - (308 + 1236)}{9} = 64 \text{ gm.}$$

C. The Influence of the Diet and of the Metabolic Mixture upon the Body Weight

When the metabolic mixture and the diet are identical there will be no loss or gain of body tissue. But this condition practically never exists. The metabolic mixture may differ from the diet, first with respect to calories, second, with respect to composition. By comparing the intake and outgo of nitrogen, one determines whether protein has been added to or lost from the body. For example, a subject who eats 50 grams of protein and who thus takes in 8.0 grams of nitrogen and whose nitrogen excretion is 10 grams, will deplete his body of 2 grams of nitrogen or 12.5 grams of protein. If this same subject received 1,500 calories and his total heat elimination were

2,000, it would be necessary for him to derive 500 calories from the oxidation of body tissue. He has already obtained from that source the heat resulting from the oxidation of 12.5 grams of protein, or 50 calories. Therefore, 450 calories must be derived from the oxidation of carbohydrate or fat, or a mixture of these two. When the conditions are such that glycogen might be used to furnish energy, there is at present no satisfactory method suitable for twenty-four hour periods of determining what fraction of the calories comes from glycogen. One may avoid this difficulty either by waiting until the glycogen stores are in equilibrium with the diet, or by keeping the diet sufficiently high in carbohydrate. Now, the remainder of the calorific deficit, viz, 450 calories, must be obtained from fat, that is 50 grams of body fat will be oxidized. This subject has lost 12.5 grams of protein and 50 grams of fat in twenty-four hours. But since these substances do not exist as dry solids in the body but in association with water, he will have released this water, heretofore physically held. The hydrophyllic colloid protein holds water equal to three times its weight, whereas body fat holds only ten percent of its weight in water. Accordingly, in this case, a loss of 12.5 grams of dry protein represents a tissue loss of 50 grams, whereas the fat tissue loss was only 55 grams. Therefore, the theoretical loss of weight of this subject would be 105 grams (50 + 55 gm.).

D. The Calculation of the Oxygen Absorbed by the Subject for the Oxidation of the Materials of the Metabolic Mixture, and of the Carbon Dioxide Yielded by this Process

The average elementary composition of the three food materials which make up the metabolic mixture is known. Carbohydrate and fat are completely oxidized to carbon dioxide and water. It is assumed that all of the carbon dioxide produced in this way leaves the body through the respiration. On the other hand, the end products of protein metabolism are lost to the body through the respiration as carbon dioxide and through the urine and stool as urea, etc. It is necessary to keep in mind the amount of oxygen needed to carry the oxidation to this stage.

In the calculation of oxygen which must be added to complete the oxidation of protein, we have used the analysis of Rubner of muscle protein. He found that 40 percent of the carbon was excreted as carbon dioxide and 11 percent excreted chiefly in the form of urea.

In CO_2, for every gram molecule of carbon there exists one gram molecule of oxygen. That is 12 grams of carbon require 32 gm. of O_2 to form CO_2. Therefore, 1 gm. of carbon requires $\frac{32}{12} = 2.7$ gm. of oxygen to oxidize it completely to CO_2. Therefore the 40 gm. of carbon would require 108 gm. of oxygen.

In urea, however, one atom of carbon is associated with

one of oxygen. That is, in urea 12 gm. carbon are associated with 16 grams of oxygen, so that 1 gm. carbon requires $\frac{16}{12} = 1.3$ gm. oxygen to form urea. The 11 gm. of carbon would then require 14.3 gm. of oxygen to form urea.

Protein contains 7.5 percent hydrogen of which 4.8 percent is oxidized to water, the rest being excreted mostly in the form of urea. We have to deal only with the hydrogen which is excreted as water. Since 2 gram molecules of hydrogen unite with 1 atom of oxygen to form H_2O, 2 grams of hydrogen require 16 gm. of O_2 or 1 gm. hydrogen requires 8 gm. of O_2. Therefore, 4.8 gm. of hydrogen requires 38.4 gm. oxygen to oxidize it to H_2O.

The sum of these three amounts of oxygen necessary to oxidize the carbon to CO_2 and urea and the hydrogen to H_2O, is the total oxygen necessary to oxidize 100 gm. of protein ($108 + 14.3 + 38.4 = 160.7$ gm.).

But the protein molecule contains 21 percent oxygen, so that 100 gm. of protein would contain 21 gm. of oxygen which may be used to carry out these oxidations, so that the oxygen which must be absorbed becomes the difference between the total oxygen necessary to oxidize the protein and that already present in the protein molecule, $(160.7 - 21) = 140$ gm.

Since for 100 gm. protein, 40 gm. of carbon are oxidized to CO_2, there will be formed 148 gm. of CO_2.

In the case of carbohydrate and fat, since we have only respiratory carbon to deal with, the O_2 absorbed, and CO_2 given off may be calculated from the elementary composition according to the same reasoning.

If we use sucrose with a formula of $C_{12}H_{22}O_{11}$ and elementary composition C = 42%, H = 6.5%, O = 51.5%, then 100 gm. would require 114 gm. oxygen to produce 155 gm. of CO_2.

In the same way, 100 gm. of tripalmitin with a composition of C = 76%, H = 12%, O = 12% requires 289 gm. of oxygen and yields 281 gm. CO_2.

From these calculations we may derive simple constants which may be used to calculate the O_2 absorption and CO_2 output for any metabolic mixture.

Constants

Material 1 gm.	O_2 Absorbed	CO_2 Yielded
Protein	1.40 gm.	1.48 gm.
Fat	2.89 gm.	2.81 gm.
Carbohydrate	1.14 gm.	1.55 gm.

By the use of these constants, we may calculate the respiratory quotient for any given metabolic mixture. For example, we have already dealt with a metabolic mixture consisting of protein 79 gm. carbohydrate 126 gm. and fat 131 gm. Hence the oxygen absorption would be the sum of the following:

$79 \times 1.40 = 110.6$ gm.
$126 \times 1.14 = 143.6$ gm.
$131 \times 2.28 = 378.6$ gm.

632.8 gm.

and the CO_2 yield:

$79 \times 1.48 = 116.9$ gm.
$126 \times 1.55 = 195.3$ gm.
$131 \times 2.81 = 368.1$ gm.

680.3 gm.

To calculate the R. Q. the weights of the respiratory gases must be converted to the corresponding volumes.

632.8 gm. $\times$ .6998 = 442.7 liters O_2
680.3 gm. $\times$ .5094 = 346.5 liters CO_2

$$\text{The R. Q.} = \frac{346.5}{442.7} = .78$$

It is worth while emphasizing again how much information may be obtained about the metabolic processes of an individual by merely feeding a diet of known composition and by determining the total insensible loss and the nitrogen output. From this information, the total heat elimination, the sources of this heat, the theoretical changes in weight, the absorption of O_2 and the output of CO_2 and the respiratory quotient may be obtained. With this information we may go still further—we may

enter an important and interesting field—viz.—water exchange.

E. Water Exchange

The source of the water with which the organism has to deal, may be considered under three headings:

I. The supply from outside—viz. water of the food and the drink.

II. Water of Oxidation—viz. that formed from the oxidation of the hydrogen of the metabolic mixture.

II. Preformed water—viz. water already present in the organism, but previously held by tissue which is being destroyed to yield part of the energy.

The second source—the water of oxidation—must always be present. On the other hand, the supply from outside may be removed and there may be no destruction of body tissue with its consequent liberation of water.

Some disposition must be made of this new supply of water. There are four avenues for its removal from the body.

1. Urine
2. Stool
3. Expiration
4. Skin

When precisely as much water leaves the body as has become available in a given period of time, the individual is said to be in water balance. He may, however, and

generally does depart from this state in one or the other direction.

Determination of the Available Water

1. The amount of water ingested as such is carefully weighed and the water of the food determined or calculated from standard tables of analysis.

2. The water of oxidation is calculated from the metabolic mixture. Since we know the average elementary composition of fat, carbohydrate, and protein, we may calculate the water formed from the oxidation of hydrogen contained therein. Those values are as follows:

1 gm. protein yields .41 gm. H_2O
1 gm. fat yields 1.07 gm. H_2O
1 gm. carbohydrate yields .60 gm. H_2O

The water yielded by the metabolic mixture already dealt with, is partitioned as follows:

79 gm. protein yield 32 gm. H_2O
131 gm. fat yield 140 gm. H_2O
126 gm. carbohydrate yield 76 gm. water
Total = 248 gm. H_2O

3. The preformed water is calculated from the tissue destruction. As has been mentioned before, every gram of body protein holds in physical combination three grams of water; and every gram of body fat, one-tenth of one gram of water. For example the destruction of 12.5 gm. of body protein releases 37.5 gm. of water, while the destruction of 50 gm. of body fat releases 5 gm. of water.

Therefore a total of 42.5 gm. of preformed water must be added to the available water. It is interesting to note that this subject, then, had to deal with (248 + 42.5) = 290.5 gm. of available water which came from sources other than the drinking water and the water of the food.

Determination of the Outgoing Water

1. The excretion of water by kidney and bowel is determined by subtracting the solids from the total weight of urine and stool.

2. The water excretion through the lungs and skin is determined as a single item and termed the Insensible Water.

The methods for the calculation of insensible loss, carbon dioxide output, and oxygen absorption have already been described. With these three values at hand, the weight of the insensible water is easily obtained. The insensible loss of weight of a subject was 1176 gm. for twenty-four hours. During this same period, his metabolic mixture was protein 79 gm., fat 131 gm., and carbohydrate 126 gm. The oxygen absorbed to complete the oxidation of this metabolic mixture weighed 633 gm., and the carbon dioxide output was 680 gm. The insensible water may be calculated by substituting in the equation thus:

Insensible H_2O = Insensible Loss — CO_2 + O_2

Insensible H_2O = 1176 — 680 + 633

Insensible H_2O = 1129 gm.

Water Exchange

An example of the water exchange for a twenty-four hour period in a normal resting man follows:

Available Water		*Outgoing Water*	
Water Drunk.....	448	Water of Urine.....	822
Water of Food.....	1312	Water of Stool.....	0
Water of Oxidation...	233	Water Insensible.....	1205
Water Preformed.....	34		
			2027 gm.
Total	2027 gm.		

It is interesting to note the relation of the insensible water to the total outgoing water. Sixty percent of the total water excreted was eliminated through the lungs and skin.

In this instance, the total water output was exactly equal to the available water. In other words, the individual may be said to be in water balance.

However, this is usually not the case. There may be an output of water greater than the available water. That is, a removal of water from the general water stores of the body. Or there may be an addition to the water content of the body.

If the water exchange of an individual is calculated from day to day under the same conditions, these fluctuations in water content of the body become apparent. This same subject in a five day period taken at random, exhibited the following variations. On the first day he retained 6 gm., on the second day 221 gm., on the third,

fourth, and fifth days, he depleted his store of water by 227, 61, and 60 gm. respectively.

One must realize that when the subject receives more food than he needs to supply his energy requirement, he stores the excess and his new tissue attaches to itself a definite amount of water. In such a case one may picture the available water being diminished by the amount of water which the newly formed tissue holds. This process is merely a reversal of that in which preformed water becomes available to the organism.

The fraction of the available water which has been termed "preformed water" may therefore be either a plus or minus quantity and the standard protocol for the determination of water exchange becomes:

Available Water	*Outgoing Water*
Water Drunk	Water of Urine
+Water of Food	+Water of Stool
+Water of Oxidation	+Water Insensible
±Water Preformed	

CHAPTER VIII

THE SYSTEMATIC DETERMINATION OF THE CHARACTER OF THE CYCLIC EXCHANGE OF ENERGY BETWEEN MAN AND THE OUTER WORLD

IT SHOULD now be clear to the reader that simple methods permit (1) the determination of the total transformation of energy by man, (2) the kinds and amounts of materials oxidized by him in order to convert potential into kinetic energy, (3) the relation between the inflow of potential energy as food and the total transformations of energy, and (4) the amount of tissue contributed by the organism when the inflow of energy is less than the outflow; or the amount of new tissue formed when the converse is true.

Since the organism draws upon its own stores in case the supply of energy falls short of the transformation; or lays by potential energy as new tissue, if the converse be true; the attempt has often been made to measure these processes by means of a record of the body weight. This simple correlation does not exist because the relationship is confused by another factor. The organism not only exchanges energy but also water with the world. Since the change in weight caused by the latter process may be greater than that caused by the former, it is evident that

a quantitative statement of the addition to the body of water or its loss, is essential in order that the numerical effect of the water exchange on the weight of the body may be evaluated. It is however impossible to know the water balance without a knowledge of the metabolic mixture. This, in turn can only be determined after the total transformation of energy for the period is available. The body weight freed of the effect of water cannot then be obtained without a knowledge of the extent of the total energy transformations. When the latter is known, changes in body weight add no new information.

The interrelationship of the exchanges of energy, the movement of water, the total changes of weight, and the moiety attributable to water may be seen in the following study.

The subject was a normal young man who remained quietly in bed. His diet consisted solely of milk, sugar, and water.

In order to obtain the desired information, the following determinations were made, which comprises one twenty-four hour period:

1) The Weight and Composition of the Diet:
   Weight = 2042 gm.; Protein = 63 gm.; Fat = 26 gm.; Carbohydrate = 148 gm.; Calories = 1078
2) The Weight of the Total Intake of Water:
   Water of the Food = 1791 gm. Drink = 147 gm.
3) The Weight of the Urine and Stool:
   Urine = 1422 gm.; Stool = 0

4) The Weight of the Urinary and Fecal Water: Urinary Water = 1382 gm.; Fecal Water = 0 gm.
5) The Nitrogen Excretion = 11.8 gm.
6) The Net Weight of the Subject every twenty-four hours. Beginning = 57.515 kg. End = 57.245 kg.

With these figures the following calculations were made:

1) The Twenty-four Hourly Transformation of Energy, determined from the insensible loss of weight = 1815 calories.
2) The Caloric Deficit = 737 Calories
3) The Metabolic Mixture:
Protein = 74 gm. Fat = 103 gm. Carbohydrate = 148 gm. Calories = 1815
4) Dry Materials from body: Protein = 11 grams; Fat = 77 grams.
5) Body Tissue Destroyed: Hydrated Protein = 44 grams, Hydrated Fat = 85 grams.
6) Predicted Loss of Weight due to Destruction of the body tissue = 129 grams.
7) Actual Loss of Weight of subject = 270 grams.

It should be noted that the actual loss of weight is more than twice the weight of body materials destroyed.

The next procedure is to deal with the exchange of water and its relation to the change in body weight. The total water available for disposal during this period was 2208 grams which was made up of the following fractions:

Water ingested = 1938 gm. Water of Oxidation = 229 gm. and Preformed Water = 41 grams.

The Total Water Excretion for the same period was 2361 grams, of which 1382 were excreted in the urine while 979 grams left the body as vapor.

The body was accordingly depleted of 153 grams of water.

If the tissue loss (129) be added to the water loss (153) the figure 282 grams is obtained. The analytical data thus account for the actual difference in the weight of the subject at the beginning and end of the period; and are accordingly a confirmation of the quantitative character of this analysis.

The application of this method of study to the following problem, brings clarity to the understanding of a phenomenon which has hitherto led the physician into error. It has been stated that a certain number of the most obese individuals encountered are suffering from a metabolic aberration which prevents them from losing weight even though the supply of potential energy is far less than the transformation of energy by them. Were this a statement of fact it is evident that such individuals would be capable of evading the principle of the conservation of energy. Hence, the question whether such a condition can ever occur in living creatures, even though it is unknown in the physical world, becomes a much more important one than the narrower one of how to treat obesity.

A subject of this type who became available for study

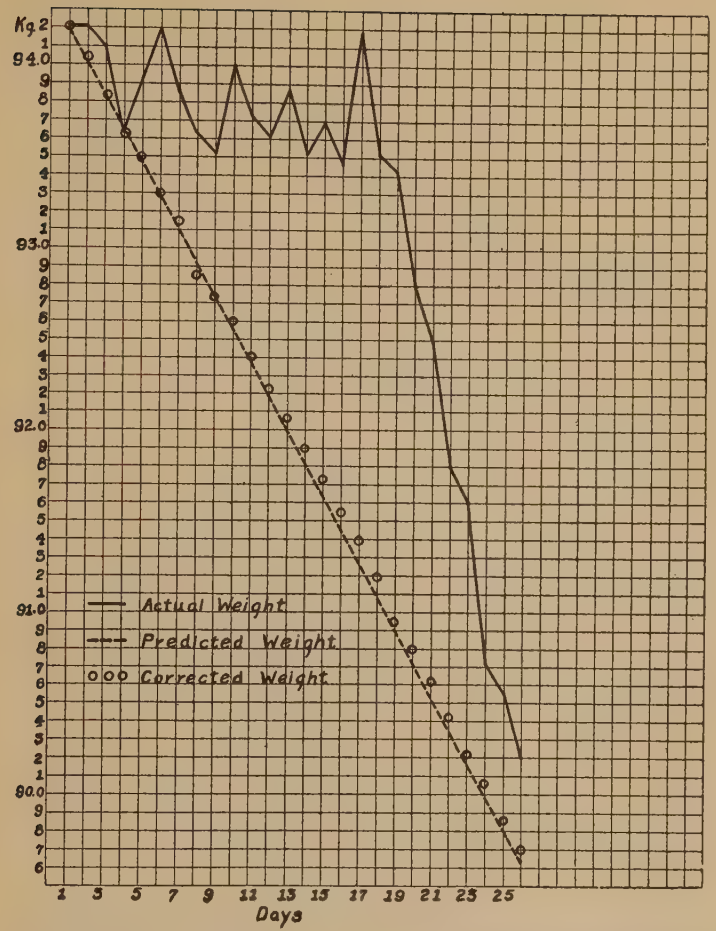

Figure II—The weight curves of an obese girl who also manifested definite endocrine disease. The broken line represents the loss of weight resulting from tissue destruction alone. The solid line indicates the subject's actual weight. The circles show what the girl would have weighed each day had her weight not been affected by the retention of water. In the first sixteen days she added to her body close to three kilograms of water. Subsequently, during the phase of rapid loss of weight she rid her body of more than two kilograms of the water previously retained.

was a highly abnormal girl of fourteen who weighed 207 pounds. The accompanying diagram shows that this patient was in fact able to maintain her initial weight over a period of sixteen consecutive days even though she received 1223 calories less than she transformed each day. During these sixteen days she destroyed 2896 grams of body tissue. Further observation brought out the fact that the failure to lose weight under these conditions was satisfactorily and simply explained by the coincidental retention of nearly three liters of water. Without any changes in the conditions so far as the observers were concerned she then abruptly entered a second phase lasting ten days during which she lost four kilograms, even though the destruction of body tissue amounted to only 1629 grams. In this phase the patient depleted her body of more than two of the three liters of water which she had previously stored.

It is evident that the course of the body weight is nothing more nor less than the quantitative resultant of the interplay between the destruction of tissue and the interchange of water. Repeated studies of this character have invariably yielded the same information. One must therefore conclude that the human subject is constrained to obey the universal law of the conservation of energy in its strictest interpretation.

CONCLUSION

A HUNDRED and fifty years ago, educated man looked upon the life process as an incomprehensible mystery. Lavoisier marks the transition from this middle age bewilderment to the modern clear cut conceptions. His understanding of the relationships between oxygen and heat unlocked the gates which permitted his followers to enter upon the open road of progress based on experimental fact. But as late as 1850, two special students, Regnault and Reiset, who were attempting to make quantitative measurements, gloomily concluded that the processes of oxidation in the living organism were too complicated to be unraveled. Nevertheless, it was soon learned that the law of the conservation of energy applied with equal force to living creatures and the inanimate world; that man has an established basal metabolic rate; that his internal temperature is fixed; that he is limited to residence on the surface of the earth since ascent of only a few miles deprives him of an adequate supply of oxygen and descent into the earth soon brings him into a region so hot he can no longer avoid hyperthermia. Further the magnitude of these requirements and relationships has been learnt.

The constant internal temperature is clearly the result of the balance between the heat of oxidation and the loss of heat from the body. Both the production and loss of heat are measurable and a disproportion between the two

has been shown to be productive of a change in internal temperature. Only in the case of disease however is there a significant shift in it. Since the organism produces vastly different quantities of heat under varying circumstances and since it is exposed to an atmosphere which may vary in temperature more than one hundred degrees, it is clear that the warm blooded animal is possessed of a highly successful mechanism for controlling the dissipation of the heat produced. Investigation now in progress in our own country is concerned with the details of this question.

AUTHOR INDEX

A

Abderhalden 26
Atwater *17, 22, 23,* 24
Aub 25

B

Benedict, F. G. *23, 24, 26,* 56, 64
Berthelot 18
Bidder 12
Black, Joseph *7*
Boothby 26
Bryant 23

C

Cahours 12
Cavendish *7*
Coleman 25

D

Despretz 10
DuBois *25, 41, 47,* 49
Dulong 10
Dumas 11
Dye 38

E

Eijkman xiii

H

Helmholz 21
Hölst xiii
Hopkins xiii

J

Johnson, S. W. 22

K

Krogh 26

L

LaPlace 9
Lavoisier 6, 8, 10, 22, 45, 95
Liebig 12, 17
Loewy 32
Lusk 17, 24, 25, 33, 45, 46

M

Magendie 11
Marât 6, 10
Mayer 21
Means 25
Mendel 26
McCann 25, 43
McCollum, E. V. ..... xiii, 26

P

Pettenkofer 13, 16, 20
Priestly 7

R

Regnault 11, 13, 95
Reiset 11, 13, 95
Root 56, 64
Rosa 23

Rubner 17, 18, 19, 20, 21, 22, 23, 24, 38, 40, 45, 80
Rutherford 7

S

Scheele 7
Schmidt 12
Schumburg 33
Seguin 9
Sherman, H. C.....xiii, 20, 26
Stahl 6, 7, 9
Strouse 38

T

Talbot 26

V

van't Hoff..... 49
Voit, Carl.....12, 13, 16, 17, 20
Voit, E..... 38

W

Wang 38
Whipple 26

Z

Zuntz 33

SUBJECT INDEX

A

Amino acids, effect on heat production 46

B

Basal state, conditions implied 65

C

Calorie, defined 4
Calorimeter, the first constructed 23
underlying principles of 35
Calorimetry, first experiment in animal 9
indirect, a true measure of total transformations 36
Calorific values, of carbohydrate and fat (Rubner) 18
of protein (Rubner) 20
modified values of carbohydrate, fat, and protein (Sherman) 20
of liter of oxygen, calculation of 28
Calculations 14, 16, 34, 46, 47, 48, 77, 83, 87, 90
of the oxygen required for the oxidation of the metabolic mixture, and of the carbon dioxide yielded 80
Combustion, Lavoisier's conception of 9
Constants 82

D

Dephlogisticated air 7
Diet, its connection with ventilation of lungs 26
Dietetics xiii
Disease and metabolic rate 42

E

Efficiency, of the human machine 4
Energy, general considerations 3
interrelationship of the exchanges of energy, the movement of water, total changes of weight, etc. 90
transformations, established rate of 5

F

Fasting, materials oxidized by fasting organism 11
Fat, measurement of amount destroyed 13
body, weight of water held 79
Fever, mechanism clarified 25, 49
causes and maintenance of increased heat 47
van't Hoff's Law 49
Figures 1, 2, 69, 93
Food, definition of xi
importance of its quality xi

G

Glucose, calorific value of 18
calorific value of oxygen for 28
respiratory quotient of 29

H

Heat elimination, determination of 35
wet method defined 66
dry method defined 66
role played by vasomotor apparatus 67, 68, 69
role played by humidity of atmosphere 70
role played by environment 70
Heat production, determination of 27, 33
a fixed rate, why? 41
and thyroid gland 41
and thyroxin 42
throughout the 24 hours 43
during sleep 43
during performance of work 43
ingestion of food 43, 45
in fever 47
relationship to insensible loss of weight 55
in relation to surface area 38, 39, 40
water vaporized in amounts directly proportional to 59

Herbivora, relation between oxygen intake and carbon dioxide outgo 10
Hibernation 51
Hyperthermia, defined 50
a method of producing, mechanism of 50
Hyperthyroidism and metabolic rate 42
Hypothyroidism and metabolic rate 42

I

Indirect calorimetry, apparatus of (Regnault and Reiset) .. 11
apparatus of (Pettenkofer and Voit) 14
Insensible loss of weight, due to 57
equation for 57
measure of heat elimination, in the basal state 57
measure of heat elimination, for 24 hourly period 72
effect of temperature on 65
effect of humidity 70
effect of air currents 70

L

Law of Conservation of Energy, holding for the animal organism 21

M

Metabolic rate, basal, defined 41
variations in 42
in disease 42
in hyperthyroidism 42
in hypothyroidism 42
Metabolic mixture, defined 74
necessity of knowing the nature of 29
calculation of, under various conditions 75
Metabolism, protein, effect of muscular work 17
basal 40

N

Nitrogen, of excreta, true measure of protein metabolism ... 12
caloric value of urinary 32
Nutrition, science of, with what concerned xi

O

Oxidation, source of animal heat 11
supply of oxygen not determining rate of 17

P

Protein, quality of xii
requirement not increased by work xiii
not stored for future use xiii
excessive use of animal tissue xiii
ideal intake xii
hydrophyllic colloid, amount of water held 79
determination of calorific value of 19

R

Respiratory quotient 30
non-protein 33, 75
effects of variations upon the relationship of the weight of the water vapor to the total insensible loss of weight 60, 61, 62, 63
of carbohydrate 29
of fat 29

S

Salts, inorganic, needed by the organism xiii
Specific Dynamic Action 22
Storage, of potential energy 5
of protein, fat, and carbohydrate xii
Sucrose 82
Surface area, relationship to heat production 22, 38, 39, 40
tables 38, 39

T

Tables, surface area 38, 39
predicted heat production 56
relation between heat lost by vaporization of water and total loss of heat in the basal state 58
relation between heat lost by vaporization of water and total loss of heat in the 24 hour state 74
constants for calculating RQ for any given metabolic mixture 82
Temperature, environmental 68
internal 95
Theories, phlogiston 6
incorrectness of 9
Thyroid diseases, clinical value of determining metabolic rate, in 25
Thyroid gland and fixed rate of heat production 41
Thyroxin, calorigenic value of 26
Tripalmitin 82

V

van't Hoff's Principle 49
Vitamines, necessary for the organism xiii

W

Water, supply from outside 84
of oxidation 84
preformed 84
balance, defined 84
determination of available water 85
Water exchange 84
Weight, gains and losses, insensible 72
sensible 72
calculation of theoretical change in weight 78
Work, muscular, no increase in protein metabolism 17

THIS BOOK

THE EXCHANGE OF ENERGY
BETWEEN
MAN AND THE ENVIRONMENT

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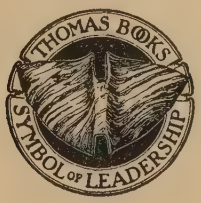

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